DEVELOPING THE COMPREHENSIVE QUALITY OF LIFE MODEL FOR ELDERLY BASED ON MODALITY OF MOTIONS, COGNITIVE ABILITY, AND HEARING LOSS

A Dissertation

by

NO YOUNG YOU

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ABSTRACT

Approximately 70% of U.S. adults over 65 are struggling with at least mild hearing impairment. This results in decreased health-related quality of life because hearing loss is closely associated with physical activities, cognitive abilities, and the risk of falling. Recent research has indicated the potential causal links among hearing, mobility, cognitive capacity, and health-related quality of life. However, their correlations are not fully understood.

This study aims to collect pilot data on hearing loss, falling, functional movement, cognitive capacities, and quality of life among elderly participants. This study shows the comprehensive model of a link among hearing deficits, physical/cognitive capacities, and health-related quality of life. A comprehensive quality of life evaluation model can allow the elderly to improve day-to-day quality of life even with potential bodily function declines. The findings fill in the gap between functional assessments and hearing loss by providing an evidence-based comprehensive model that helps improve the quality of day to day life in elderly populations.

DEDICATION

To my wife, my son and my parents

ACKNOWLEDGEMENTS

The journey to complete my dissertation would not have been possible without the support of my family, professors and mentors, and friends.

A sincere thank you to my lovely wife Ohbet Cheon, and precious son Isaac Chanhee You for encouraging me in all of my pursuits and inspiring me to follow my dreams. I am especially grateful to my parents Moonkyu Lew, Soonjin Hong, for showing me how to trust God when walking through life. Their love and prayers have led me to walk this path and pursue my academic goals.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

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All work for the dissertation was completed by the student, under the advisement of Professor Adam Pickens of the Department of Environmental and Occupational Health.

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NOMENCLATURE

ADL	Activities of Daily Living Scale
ANOVA	Analysis of Variance
ARHL	Age-Related Hearing Loss
BEHL	Better Ear Hearing Level
BMI	Body Mass Index
COP	Center of Pressure
hEAR	Mobile Hearing Screening Application
HRQOL	Health-Related Quality of Life
IADL	Instrumental Activities of Daily Living Scale
ISO	International Organization for Standardization
IRB	Institutional Review Board
MCS	Mental Component Summary Score
MMSE	Mini-Mental State Examination
OLS	Ordered Logistic Regression
PCS	Physical Component Summary Score
QOL	Quality of Life
SEM	Structural Equation Model
SF-36	MOS 36-Item Short-Form Health Survey
SPH	School of Public Health
SPL	Sound Pressure Level
SPPB	Short Physical Performance Battery

TAMU	Texas A&M University
TMT	Trail Making Test
TUG	The Timed Up To Go
WHO	World Health Organization

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1. INTRODUCTION

Age-related hearing loss is defined as the decrease of auditory sensitivity and processing function for hearing that comes with aging [1]. Survey statistics showed that almost 70% of the elderly population in the U.S. had experienced a degree of age-related hearing loss, which is closely related to their quality-of-life [2]. Hearing loss affects not only daily tasks, but also influences mobility, their chance of falling and basic physical function that may limit their ability to move. However, the relationship between hearing loss and bodily function capacity is still understudied, and most existing studies rely on self-reported assessment through interviews [3, 4].

This research focuses on the relationship among hearing loss, bodily function capacity and health-related quality of life (HRQOL). This study collects pilot data on hearing loss, functional movement, and cognitive capacities among elderly participants. After collecting data through a series of laboratory experiments and external healthcare providers, this study seeks to develop an algorithm for predictive evaluation of the link among hearing deficits, physical/cognitive capacities, and health-related quality of life. The findings contribute to the gaps in the previous studies by providing evidence-based predictive models. This research also helps to develop deployable solutions based on predictive models of the hearing quality of life linkages among the elderly.

Existing literature indicates that hearing loss is closely related to the quality of life in the elderly because it decreases their modality and cognitive abilities. Hearing impairment is negatively associated with a possible risk factor for dementia in the elderly population [5, 6]. The age-related hearing loss also can lead to the degradation of audibility and speech understanding [2, 7]. Moreover, communication deficits in the elderly population pose a serious problem when combined with hearing loss because it affects their emotional health including depression, loneliness, and distress [8, 9, 10, 11]. However, only 20% of elderly people with hearing loss recognize that it affects their quality of life and try to seek help [12]. Therefore, the average age of using a hearing aid for the first time is approximately 75 years old [13].

Recent studies have shown that hearing impairment is associated with physical function ability. [3] found that the elderly people with hearing loss have an extent of limitations of modality through using self-report surveys. Poor postural balance and low auditory capability caused by hearing impairment may lead to unsafe situations, such as falls to the elderly population [14, 15]. Other work has shown that declining physical ability, such as lack of balance, can lead to an increased risk of falling in older adults [16]. Research also indicates that elderly individuals with hearing loss are less likely to be aware of their circumstances, and are less able to maintain balance and gait, resulting in being overwhelmed by cognitive workload [14]. Research has indicated that the Short Physical Performance Battery (SPPB) can be a quality tool for verifying a relationship between physical capability and falls by conducting a series of physical ability tests, but needs more research to strengthen the relationship shown in the initial work [17].

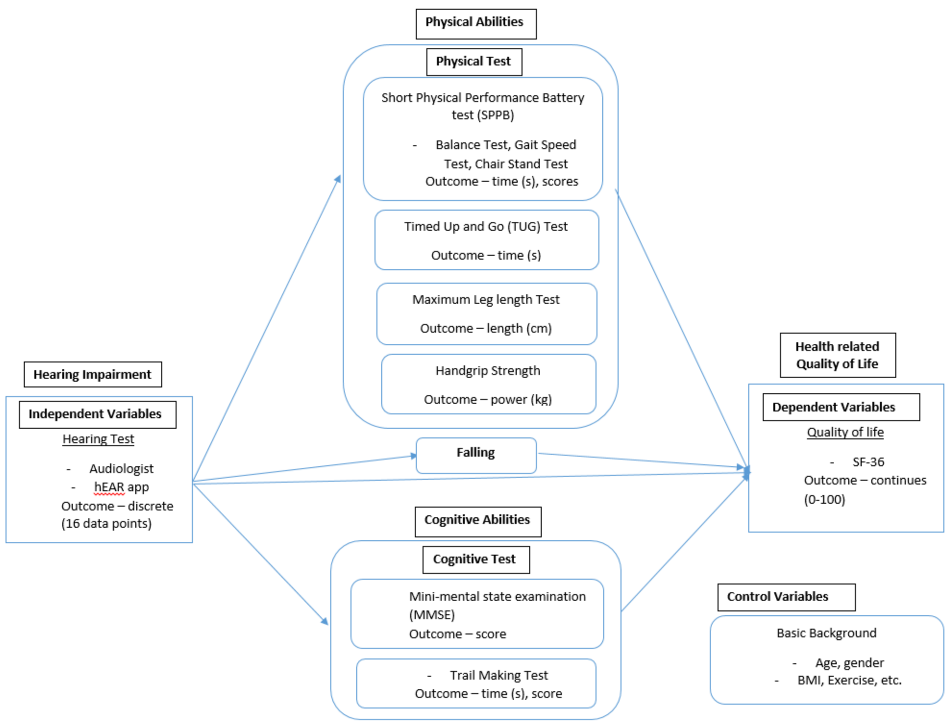
The Katz Activities of Daily Living Scale (ADL) and the Lawton Instrumental Activities of Daily Living Scale (IADL) Index survey tools commonly used to assess elderly daily living skill [18, 19, 20]. These tools are most helpful for measuring the bodily function of adults and identifying overall improvement or not of daily life skills [21]. The ADL Index has included six daily activity functions of bathing, dressing, toileting, transferring, continence, and feeding based on the scoring 0 (participant very dependent) to 6 (participant independent). IADL Index includes more complex daily life activities functional skills such as the ability to use a telephone, shopping, food preparation, housekeeping, laundry, mode of transportation, responsibility for own medications and ability to handle finances based on the scoring 0 (participant very dependent) to 8 (participant independent) [22, 23]. [24] found that hearing impairment limits daily physical functions related with ADL and IADL in the elderly population in the U.S. Studies have also found that hearing impairment is associated with an increased likelihood of falls.

Quality of life measurements do not focus on the specific diseases and health conditions but do include overall self-perceived health status. The MOS 36-Item Short-Form Health Survey (SF-36) is the most common health-related, quality of life survey tool regarding hearing loss to assess self-perceived health status. The SF-36 is made up of 36 questionnaires including eight health domains such as physical, social, usual role activities related to physical and emotional health, bodily pain, mental health, vitality and general perception of health [25, 26].

The quality of life is conditioned by the status of physical, cognitive, mental, and social health [27, 28]. Hearing impairment can significantly affect the quality of life because it can decrease bodily functional capability regarding physical, cognitive, and mental aspects [29, 2]. While early detection of hearing loss and treatment at the early stage can improve the quality of life in the elderly, it is rarely studied how to predict the impact of hearing loss on the quality of life, and how the physical/cognitive capabilities are associated with this link [30]. The comprehensive understanding of the relationship among hearing losses, physical/cognitive capabilities, and the quality of life can provide early detection of hearing impairment, and therefore improve the quality of life through increasing physical/cognitive capabilities. Figure 1.1 shows a comprehensive relationship between hearing loss and Quality-of-life based on the literature review.

This study proposes a comprehensive model for improving the quality of life in terms of the relationship between hearing loss and physical/cognitive capabilities. This study conducts a hearing test in two different ways and administers laboratory experiments in terms of physical/cognitive capabilities to investigate how hearing impairment is associated with physical/cognitive abilities. The process allows the research team to find a

Figure 1.1: Comprehensive relationship between hearing loss and quality of life based on the literature review



relationship that predicts a range of quality of life-related to their health conditions. The findings of this study provide an explanation in the personalized interventions to improve health-related quality of life. This study helps to fill the gap between functional assessments and hearing loss by providing an evidence-based comprehensive model that supports the daily quality of life in the elderly populations.

This study also uses innovative methods to provide evidence-based predictive models for the elderly population with hearing impairment in terms of health-related quality of life. Previously, most studies have focused on functional capacities using walk/gait-based tests, balance tests, and sit/stand tests [14, 15]. Such studies have revealed a significant relationship between hearing loss and the likelihood of falls, but the research settings often require separate testing appointments conducted by trained individuals. By providing empirical evidence on the relationship between hearing and functional movement capacities, this study contributes to providing a new sensing system with a capability of capturing important interdependent moments that previous studies have rarely done so far.

As the elderly population in the U.S. continues to increase in proportion, the quality of life for the elderly continues to be a top priority [31]. Existing studies indicate that health status is closely associated with quality of life metrics in elderly people such as physical, cognitive, and mental health condition [32]. Particularly, hearing loss is a prevalent issue among the elderly, since almost 70% of elderly U.S. population is diagnosed with at least mild hearing loss [33].Scholars have studied the relationship among hearing loss, physical/cognitive ability, and quality of life; however, there is still a lack of comprehensive understanding on how hearing impairment is associated with the quality of life, and in that relationship how physical/cognitive ability moderates the impact of hearing loss on the quality of life. Moreover, it is rarely studied to develop a predictive model for quality of life in the elderly based on the modality, cognitive ability, likelihood of falls, and hearing loss. These research gaps will be addressed in this study through specific research aims.

The two specific aims of the proposed research are:

Aim #1: To identify the comprehensive relationship among hearing loss, physical/cognitive abilities, and health-related quality of life in the elderly based on objective measures.

Aim #2: To develop a predictive quality of life evaluation model for the elderly based on the modality, cognitive ability, fall, and hearing loss.

This study conducts a laboratory experiment on physical and cognitive ability and administers surveys to measure participants' quality of life. This study also measures participants hearing loss through a mobile application and in a professional setting by certified audiologists. The experiment, survey, and test settings allow for determining key factors that are associated with a potential predictive model of quality of life among the elderly.

2. EXPERIMENT RESEARCH DESIGN AND METHODS

2.1 Research Setting

This research was conducted at 113 and 117 TAMU-SPH Laboratory Building and Texas ENT & Allergy (see Figure 2.1). All participants were required to visit SPH Lab Building 107 to have the opportunity to read and complete a Texas A&M University Institutional Review Board (IRB2016-0806D) approved informed consent form and basic questionnaires about their health. All experimental equipment was set up clearly, and all obstacles for the experiment were moved and cleaned in the lab before participants arrived for safety and efficiency. Total expected experiment time was about 2 hours including surveys and breaks.

Participants were also required to visit Texas ENT & Allergy for a hearing test after completing the laboratory data collection session. After completing the physical and cognitive experiments in the lab, the researcher-assisted participants set up an appointment with Texas ENT & Allergy for data collection. The overall physical and mental workloads required for this experiment were not significantly more than for common daily tasks. However, if participants felt discomfort during the experiment, they were able to request an additional break or terminate their participation at any time.

In total, 30 adults age 60-80 years old were recruited from the university and local communities. Participants were gender balanced to control gender-specific outcomes. Subjects were to be within the specified age range and have no diagnosed hearing loss with some functional movement capacity. Due to the fact that subjects were elderly, there was an expectation that there would be some functional losses in hearing and movement, but the limitations on those deficits were limited to those who were clinically diagnosed as to allow for variability in the data for algorithm development. There were several specific

Figure 2.1: Experimental lab at SPH lab building and audiometric sound booths

inclusion and exclusion criteria.

Inclusion criteria included that: 1. The participant was between 60-80 years old. 2. The participant was in normal health in terms of mobility. 3. The participant required to be English proficient.

Exclusion criteria included that: 1. Individuals with self-reported injuries or medical conditions that interfere with the data collection. 2. Individuals who use hearing aids or have been diagnosed with serious hearing impairment. 3. Individuals who use crutches, wheelchair, and any walking aid.

This study received approval from Institutional Review Board at Texas A&M for the all data collection and participant recruitment. The study was advertised through flyers and email announcements sent to listservs (TAMU). The flyers were posted at local senior centers in the community such as Southwood Community Center and local places of worship, which do not require written permission. All advertisements included the purpose and duration of the research. On the recruitment materials, the contact information of the site investigator was included so that participants can ask questions before inclusion. If participants confirmed that they wanted to participate and fulfilled the inclusion/exclusion criteria through telephone screening, the researcher provided them with a copy of the consent form to review before they attended the lab for their first session (hence, giving them ample time to review the study protocol) before signing it.

The participants were compensated $50 each for study participation when they complete all study sessions. Total participation time was no more than three total hours; approximately two hours for the lab-based component and one hour for the hearing test at the local audiologist (Texas ENT & Allergy). Two different study sessions were conducted different place at107 SPH Lab and Texas ENT & Allergy.

2.2 Experiment Session: SPH Lab Experiment

2.2.1 Experiment Procedures

All elderly participants have followed the same sequence of the experiment for the consistency of result and minimization of sequence error. Figure 2.2 show the procedure of whole experiments including surveys, hearing, physical and mental tests. Elderly participants took at least 2-minute breaks between each part of test.

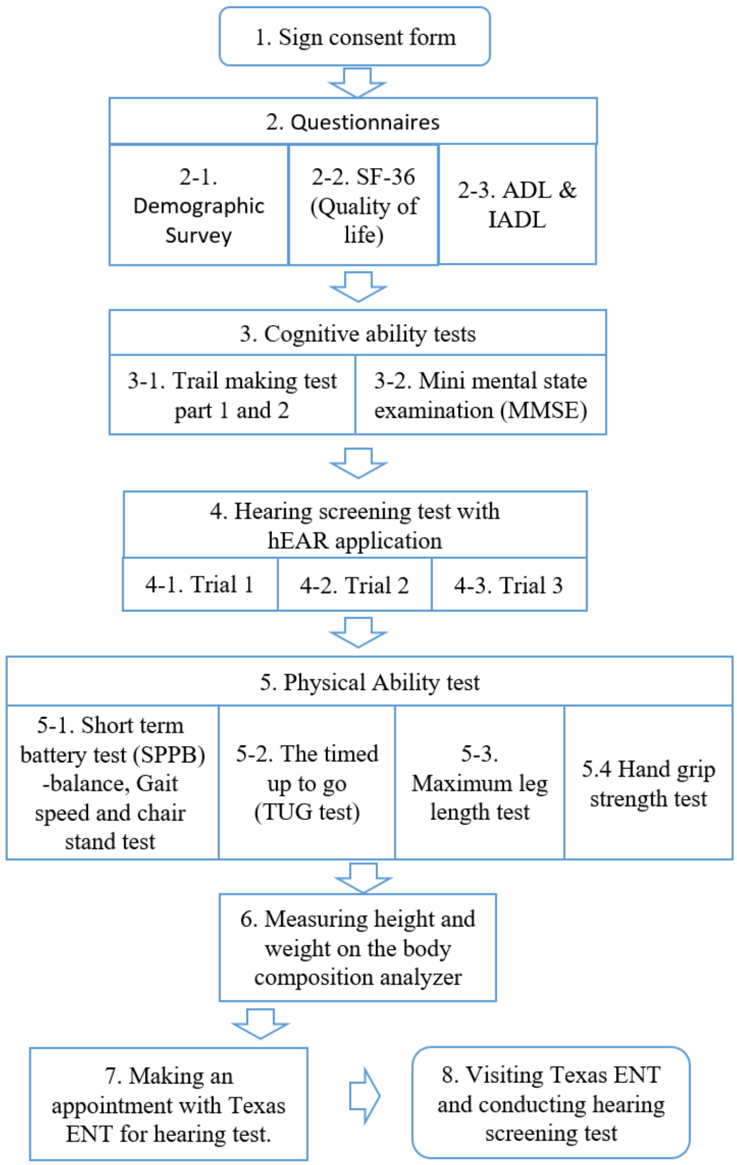
2.2.2 Demographic and Quality of Life Survey

First, all participants were asked to answer two questionnaires before participating the laboratory experiment: 1) one assessed basic background demographic information like age, gender, weight, height, and previous falling experience with workout abilities, and 2) another one is called SF36, ADL, and IADL which were part of the medical outcomes study and short form health survey [26]. By surveying these elderly participants, basic health information was collected regarding elderly participants.

During this session, informed consent, demographic and fall history, mental state examination, health testing, and anthropometric measurements were taken. Each participant was asked to finish a survey related to basic information and health condition. The researcher collected demographic information such as age, sex, race, education, and previous disease experience.

Survey data were also collected regarding previous and current elderly physical health conditions by surveying SF36, ADL, and IADL. The written questionnaires were stored in a locked file cabinet, and laboratory performance data files were stored securely on password-protected computers in the TAMHSC Human Factors Lab (SPH LAB building 107).

Figure 2.2: Procedure of overall experiments



2.2.3 Cognitive Ability Test

First, the Trail Making Test (TMT) was conducted for checking elderly mental impairment. The TMT consists of two parts, A and B. It consists of 25 circles with number and letters in each: In Test A, participants were required to draw a line to connect the circles from 1 to 25 consequently. In Test B, participants were also required to draw a line to connect the circles sequentially, but with the additional task of switching between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). The researcher recorded time to completion for both parts of the test. Completed time for parts A & B were considered deficient if the time was over 78 and 273 seconds, respectively. Previous validation research for the TMT indicates that the average completion time was 29 seconds for the trial A and 75 seconds for the trial B [34].

Participants were required to take a cognitive ability test, which measures for mental disorders and cognitive impairment. Mini-mental state examination (MMSE) is widely used as a cognitive ability screening tool for the elderly. The MMSE was composed of questions related to five cognitive abilities including orientation, attention, registration, recall, and language. The MMSE score indicates severe, moderate and mild cognitive impairment which are over 9 points, 10-18 points, and 19-23 points. The total maximum score for the MMSE is 30 [35].

2.2.4 Mobile Hearing Screening Application - hEAR

Hearing screening was conducted using an automated hearing screening application (mobile hearing screening application-hEAR) during the first session as well as in the laboratory data collection period at Texas A&M SPH. During this test, participants used a Samsung Galaxy tablet and Pioneer HDJ-2000 Headphone (Figure 2.3). The Samsung Galaxy tablet was the 8-inch model for conducting the hearing test with great sound and display. The Pioneer HDJ-2000 headphones can deliver a sound range from 5 - 30,000Hz and maximum output are 107db/mw with 36 Ω. In previous studies, the Pioneer headphones were able to reproduce results not significantly different than the audiologist in a study that used the general public. These two different types of equipment can run hEAR application software, and were able to reproduce an appropriate range of sound.

Figure 2.3: Galaxy tab 3 and Pioneer HDJ-2000 headphone

The self-administered hearing screening examination was repeated three times per subject. The collection was done through a mobile hearing screening application developed by Dr. Adam W. Pickens. The application uses algorithms to administer frequency-specific hearing screenings based on audiologist and World Health Organization (WHO) best practices of Bekesy audiology. The application has been used in two previous TAMU-approved pilot studies and has numerous safeguards for volume built into the test algorithms.

Before conducting the hearing test with the hEAR application, all participants are trained by a researcher on how to test hearing capacity. All participants then conducted simple sample random frequency trails for understanding how hEAR works. Previous pi-

Figure 2.4: 3M Quest 2800 sound level meter

lot studies indicated a negative relationship between quality of data and the background ambient sound pressure levels (SPL). It is for this reason that, the testing room chosen for this data collection needed to be below certain parameters. To verify that the ambient SPL was within normal limits, the ambient SPL of the testing room (Lab 113) was evaluated using a 3M Quest 2800 sound level meter prior to testing sessions at five different locations (see Figure 2.4, average seen in Table 2.1).

Table 2.1: The sound pressure level of testing room

Room	SPL (dB)				
113 Lab	17	22	33	37	38

According to the American national standards institute (ANSI) S3.1-1999, the maximum permissible ambient noise level (MPANLs) in the hearing test room and valid hearing testing room 113 lab for conducing hearing study [36].

2.2.5 Physical Ability Test

Participants' functional strength and mobility were assessed using five different tests:

1) Balance test on the force plate
2) Short physical performance battery (SPPB) test
3) Timed up and go (TUG) test
4) Maximum leg length test
5) Handgrip strength test

Before physical ability test, weight and height of elderly participants were measured by using stadiometer and body composition analyser. By putting height data into body composition analyser, a participant's BMI was calculated automatically on the body composition analyser.

1. Balance Test

The balance test measured the degree of stability of a participant's physical ability on the force plate (see Figure 2.5). This test is composed of three sub-tests based on the position of the feet, which are side-by-side, semi-tandem, and the tandem stand position (see Figure 2.6, from Romberg test instruction). This study conducted a developed version of the balance test that was supposed to be included in the SPPB test, using a force plate, because most people achieve the highest score (normally 4/4 in terms of balance score) and does not provide any variance across participants [15]. The force plate allows for an accurate calculation of a participant's balance, and helps to measure the exact numerical value when a participant loses their balance.

All participants were able to stand without any help such as with a cane, walker, or holding another type of aid, but the researcher helped them get up before starting the test. For all three balance tests conditions (Figure 2.6), participants were required to stand in the designated foot position for ten (10) seconds on the 20"x20" force plate. Times were scored using the standard Balance Test scoring matrix (See Table 2.2)

Figure 2.5: Forceplate orientation and AMTI force plate

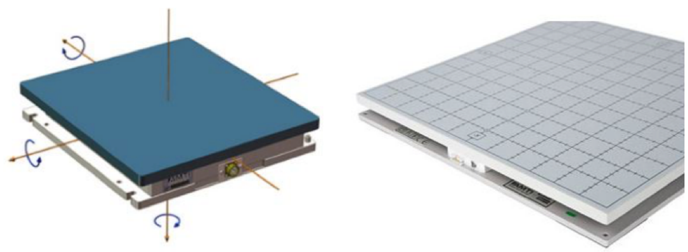


Figure 2.6: Three types of foot position for balance test

Participants were allowed to use a body part, including an arm or knee for keeping balance before measuring time, but they were required to hold their standing position until instructed to stop. If a participant stood in this position for the required time, they were then asked to transition into the semi-tandem test condition. If a participant was not able to stand for 10 seconds, the balance test was stopped. However, the balance test at the side-by-side foot position was conducted three times.

Similar to the side-by-side standing position, participants attempted to stand within the semi-tandem foot position for 10 seconds. Before starting the semi-tandem balance test, a

Table 2.2: Scoring balance test

Scoring	side-by-side	semi-tandem	tandem
Held for 10 sec	1 point	1 point	2 point
Held for 3 to 9.99 sec	0 point	0 point	1 point
Held for less than 3 sec	0 point	0 point	0 point
Not attempted	0 point	0 point	0 point

Note: If a participant earn 0 points at any trial, end balance tests immediately. [37]

participant could use external mechanisms to hold onto in order to maintain balance until the test initiation. If a participant stood for the required 10 seconds, they then transitioned into the tandem position. If a participant is not able to stand for 10 seconds, the balance test was stopped. However, the balance test at semi-tandem foot position was conducted three times.

The tandem stand position is the most difficult posture among the three different foot position balance tests. Similar to the two previous tests, this test required a participant to stand in a tandem foot position for 10 seconds. The balance test at the tandem foot position was conducted three times. After completing the balance test, the participant was allowed to rest for 5 minutes.

The researcher collected the balance data by using the AMTI force plate system (AMTI, Inc., Newton, MA) (Figure 2.6) during all three different types of balance test. The force plate provided a measurement of forces and moments from the force plate surface.

2. Short Physical Performance Battery (SPPB) Test

The Short Physical Performance Battery (SPPB) test is a well-respected and widely used battery of basic physical performance tests. SPPB has proven to be a useful tool for obtaining meaningful information about the physical assessment of older adults [37, 38]. The researcher measures time-based outcomes on the SPPB and then translates those times into a score based on a standard scoring metric (Table 2.3). The test outcomes were scored on a range between 0 (worst performance) to 12 (best performance) by combining all scores. The score ranges were as follows: very low physical function (0-3), low physical function (4-6), moderate physical function (7-9) and high physical function (10-12).

Table 2.3: Scoring total SPPB test and gait speed test

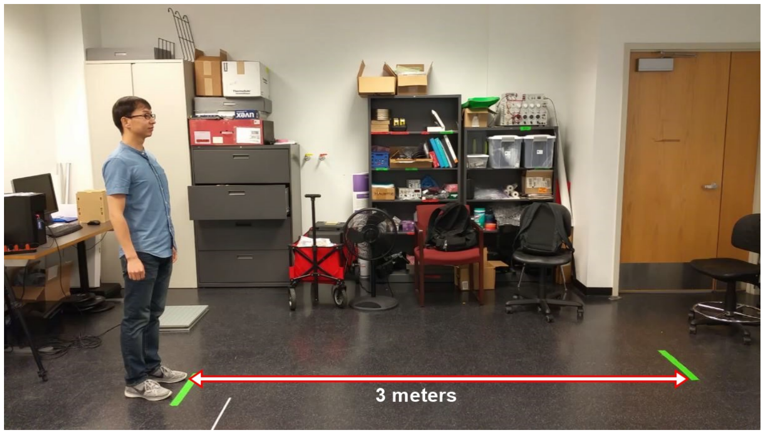
SPPB Total score interpretation	Scoring Range
Very low physical function	0-3
Low physical function	4-6
Moderate physical function	7-9
High physical function	10-12
Scoring for the 3-meters gait speed test	Score
If time is more than 6.52 sec	1 point
If time is 4.66 to 6.52 sec	2 point
If time is 3.62 to 4.65 sec	3 point
If time is less than 3.62 sec	4 point
Scoring for the 3-meters gait speed test	Score
If a participant cannot complete single chair stand test	0 point
If a participant unable to complete 5 chair stands	0 point
If chair stand time is 16.70 sec or more	1 point
If chair stand time is 13.70 to 16.69 sec or more	2 points
If chair stand time is 11.20 to 13.69 sec	3 points
If chair stand time is 11.19 sec or less	4 points

Reference from [37]

The SPPB must be performed in sequential order to ensure test reliability and consistency. These tests included balance, gait speed, and chair stand tests. Among these subsets of the test, the researcher conducted the balance test as described in the previous section using a force plate.

After a 5-minute break from the balance test, participants performed the gait speed test three times. A participant walked a total of 3 meters at their normal gait pace. 3 meters were recorded after starting sign to the participant (Figure 2.7).

Figure 2.7: Gait speed test



The gait speed test was conducted three times. The researcher recorded all trials using a video recorder and later analyzed for time to cover the 3-meter distance. The average recorded time was transited into the score. Times were scored using the standard Gait Speed Test scoring matrix (Table 2.3)

The Chair Stand Test measures the strength of the legs of participants by standing up from a seated position in a chair without using their arms. Participants were required to fold their arms across their chest during the chair stand test. First, participants stood up from a chair with their arms folded across their chest. If the participant can perform a single chair stand, then the researcher progressed to the Repeated Chair Stands test. Repeated Chair Stands test measures time from initiation to completion for a stand/sit cycle completed five (5) times from the chair with their arms folded across their chest within 1 minute. Participants were required to stand from the seated position to fully upright as quickly as they can with their arms folded across their chest. If a participant uses their arm or takes over 1-minute time to complete the five repetitions, the Chair Stand Test was stopped. Times were scored using the standard Chair Stand Test scoring matrix as noted in Table 2.3.

3. Timed Up and Go (TUG) Test

For the TUG Test, participants were required to stand up from a seated position in a chair, walk 3 meters at their normal pace, and return the seated position in the chair. The time of completion of the full cycle was measured. If a participant takes over 12 seconds to complete the TUG test, it is assumed that he or she is at a high risk for falling [39].

4. Maximum Leg Length Test

The maximum leg length test measures the stretching length for a participantâĂŹs balance with strength and flexibility. Participants were required to maintain their balance by using one leg while reaching the other leg as far as possible in front, backward, and on each side of the test leg. When their right leg was tested, they were required to reach the front, back, and right side. Oppositely, they were required to reach the front, back and left side with left leg. For all three movements away from the center, the distance from the center, the maximum distance (cm) participants could reach their toe place while maintaining their balance. Data were collected for the Maximum Leg Length test for three different directions [40].

5. Handgrip Strength Test

Handgrip strength is important for older people to hold, grab, and lift. Participants were involved in a maximum isometric handgrip strength test. A handgrip dynamometer was used for measuring handgrip strength for each participant two times for both hands (Figure 2.8). Participants were required to maintain maximum handgrip force by squeezing the handgrip dynamometer for 5 seconds. Before the hand grip test, handgrip dynamometer was adjusted to the participant's hand size. The participants were required to squeeze dynamometer with the arm at the 90 degrees near body trunk. Data were recorded for the maximum handgrip force on dominant hands [41].

Figure 2.8: Handgrip dynamometer

2.3 Experiment Session: Texas ENT & Allergy Lab Experiment

At this session, hearing screenings were performed during a separate appointment at a different location (Texas ENT & Allergy; 1730 Birmingham Dr. College Station, TX 77845) by certified audiologists using standardized professional equipment and techniques across individual frequencies (125, 250, 500, 1000, 2000, 4000, and 8000 Hz). Hearing screenings took approximately one hour with the local audiologist, Dr. Christi Madsen. Ms. Rema Lara, her technician, assisted in the testing while being supervised by Dr. Madsen at Texas ENT & Allergy.

Hearing screenings took approximately one hour at the local audiologist, Dr. Christi Madsen. Ms. Rema Lara, her technician, also conducted the testing while being supervised by Dr. Madsen at Texas ENT & Allergy. Elderly participants who have good hearing took the hearing screening test for 15-30 minutes, while someone with hearing loss took up to 1 hour.

The hearing screening portions of the data collection offer no known risks, as both are well-established screening methods. Additionally, participants have the option to receive their hearing screening results from the audiologist at no cost to them.

2.4 Statistical Analysis Methods

Several statistical analysis methods were used for data analysis. A repeated measures ANOVA model was used for the statistical analysis in order to compare trials. The key independent variable is hearing screening, which has seven different data points with sound pressure levels (SPL) for each ear (125, 250, 500, 1000, 2000, 4000, and 8000Hz). The dependent variables were Sound Pressure Levels (SPL) at trial 1 (a reference data from audiologists), trial 2, 3 and 4 (data from the hEAR app) with the repeated seven frequency measurements. The frequencies were used as repeated variables. By controlling for error terms, each variable interaction term was used for residual error. The repeated measures ANOVA test was conducted four times for testing hypothesis 1 and 2 [42].

Ordered logistic regression was used for analyzing the quality of life data sets after transforming the different types of a dependent variable into a categorical variable because most of the dependent variables related to the quality of life score were not normal.

The AMTI force plate provided six different axis biomechanics movements of the center of pressure (COP) outcomes, such as mediolateral, anteroposterior and vertical for plate moment regarding x, y and z. Based on the collected COP, the three different variables were measured and calculated as the average of mediolateral velocity, anteroposterior velocity (mm/s) and velocity moment (in term of x and y-axis on each three types of foot positions side by side, semi-tandem and tandem position) [15]. Each participant conducted a balance test on the AMTI force plate with 500Hz per second for the 12 second. Due to the noise of data in the beginning of the test and the end of the test each one second, only 10 second of balance data were used in this experiment. Each data set including moment x- and y- axis was applied 4th order Butterworth low pass filter with cutting off 5000Hz frequency [66]. After applying the filter, mediolateral and anteroposterior velocity (mm/s) and velocity moment (mm2/s) were calculated using COP force plate data. Binary variables for fall experience were included using the participant's demographic survey. Since the fall experience variable rarely showed a variation across participants due to their healthy pre-conditions, dummy variables as binary types are more efficient to find a relationship between hearing loss and fall experience. Based on the data characteristics, the COP movement and fall data were calculated and compared in the different BEHL grades. Multivariate linear regression was used for physical and cognitive ability analysis.

2.5 The Description on Participant Demographic Information

In total, thirty (30) participants were recruited for the study participation. The study was gender balanced with fifteen male and female participants. Table 2.6 show the summary of the participant's demographic information. In total, 70% of participants were below 70 years old and 30% of participants were over 70 years old. Over the 80% of participants reported an education level of at least college graduate or higher because many of the participants were recruited from the Texas A&M University.

Table 2.5 indicates the summary of the participant's exercise and fall history information. In total, 25 participants have regularly exercised for at least two years. 40% of participants had experienced a fall from their daily activities within one year.

Table 2.4: The summary of participant demographic information

Gender	
Male	15 (50%)
Female	15 (50%)
Age	
60 - 65	11 (36.67%)
66 - 70	10 (33.33%)
71 - 75	5 (16.67%)
76 - 80	4 (13.33)
Marital Status	
Married	21 (70%)
Widowed	4 (13.33%)
Divorced	5(16.67%)
Education level	
High school graduate	1 (3.33%)
Some college or vocational school	4 (13.33%)
College graduate or higher	25(83.33%)

Table 2.5: The summary of participant exercise and fallen information

Presenting exercise	
Yes	25(83.3%)
No	5(16.6%)
Exercise duration	
less than 3 months	2 (6.67%)
3-6 months	0 (0%)
6-12 months	0 (0%)
more than 1 year	4 (13.3%)
more than 2 year	19 (63.3%)
Exercise per week	
1	0 (0%)
2	2 (6.6%)
3	12 (40%)
4	3 (10%)
5	2 (6.6%)
6	2 (6.6%)
7	4 (13.3%)
Exercise Time	
Less than 15 min	1 (3.3%)
15-30 min	5 (16.6%)
30-45 min	8 (26.6%)
45-60 min	6 (20%)
over 60 min	6 (20%)
In the past month, how many times have you fallen?	
0 (never)	26 (86.6%)
1 (one time)	4 (13.3%)
In the past year, how many times have you fallen?	
0	18 (60%)
1	7 (23.3%)
2	4 (13.3%)
4	1 (3.3%)
How many of these falls caused an injury?	
0	18 60%)
1	7 23.3%)
2	4 13.3%)
4	1 3.3%)
How fearful are you of falling?	
Not at all	21 (70%)
A little	9 (30%)
Somewhat	0 (0%)
A lot	0 (0%)
Falling interfered with your normal social activites	
Extremely	2 (6.6%)
Quite a bit	0 (0%)
Moderately	0 (0%)
Slightly	1 (3.3%)
Not at all	27 (90%)

3. VALIDATION FOR THE PURE-TONE HEARING APPLICATION (HEAR) ON THE TABLET AMONG ELDERLY PARTICIPANTS

3.1 Introduction

Over 50% of the elderly population has at least mild hearing loss in United States of America by [43]. Age-related hearing impairment is one of top ten illnesses in elderly population [44]. Hearing impairment is associated with physical and cognitive ability. However, 80% of the elderly population with hearing impairment do not recognize that their quality of life is affected by hearing impairment [12]. Thus, the average age of using a hearing aid for the first time experiencing hearing loss is about 75 years old [13].

According to [45], age is a key determinant of hearing loss, but there are other related occupational factors such as the incident on the ear and noise environmental condition. The most common reason for hearing loss among the elderly population is presbycusis or age-related hearing loss. However, exposure to noise, job type, and disease are also key factors of hearing impairment. Thus, appropriate hearing screening methods can be different depending on the characteristics of participants and conditions.

Since hearing impairment can negatively affect cognitive, physical, emotional functional abilities [46], early detection of hearing loss is important for the elderly. The Pure-Tone Audiometry hearing test is the validated gold standard of hearing screening tests [47], but it is relatively expensive and time-consuming to visit an audiologist for conducting a hearing screening examination. With this being the case, other scholars have developed self-administrated hearing surveys [43, 48]. However, studies have shown that older adults are more likely to under-report their hearing problems [49] in subjective surveys.

Recently, scholars have been developing options for porTable hearing screenings. For example, [50] invented a smartphone specialized in hearing screening technology particularly for portable hearing screening in school children ($hearScreen^{TM}$). This smartphone application is easy to access with less time and cost. The study reported that the application is valid and provides accurate data when they test school children's hearing ability with it.

Along this trend of research, this study conduct an experiment on the validity of the mobile hearing screening application, named 'hEAR' with 30 elderly participants. The mobile hearing screening application was developed and pilot tested by Dr. Adam W. Pickens at Texas A&M University over recent years. The application uses algorithms to administer frequency-specific 125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, and 8000Hz hearing screenings based on audiologists and World Health Organization's (WHO) best practices. The hEAR application has been validated by two pilot studies with the general population, and has numerous safeguards for volume built into the test algorithms, yet the validity and reliability tests are required specifically with elderly participants.

3.2 Hypotheses

The hEAR mobile application could potentially be an innovative way for early detection of hearing loss among the elderly. To apply the hEAR application in the practical way, it needs to be tested with regard to reliability and validity within this population. Thus, there are two hypotheses that require testing.

$H_0 - 1$: There is no significant different between the sound pressure level (SPL) trials from the hEAR application: reliability hypothesis

$H_0 - 2$: There is no significant different between the sound pressure level (SPL) from audiologist's hearing screening data and SPL from the hEAR application: validity hypothesis

3.3 Methods

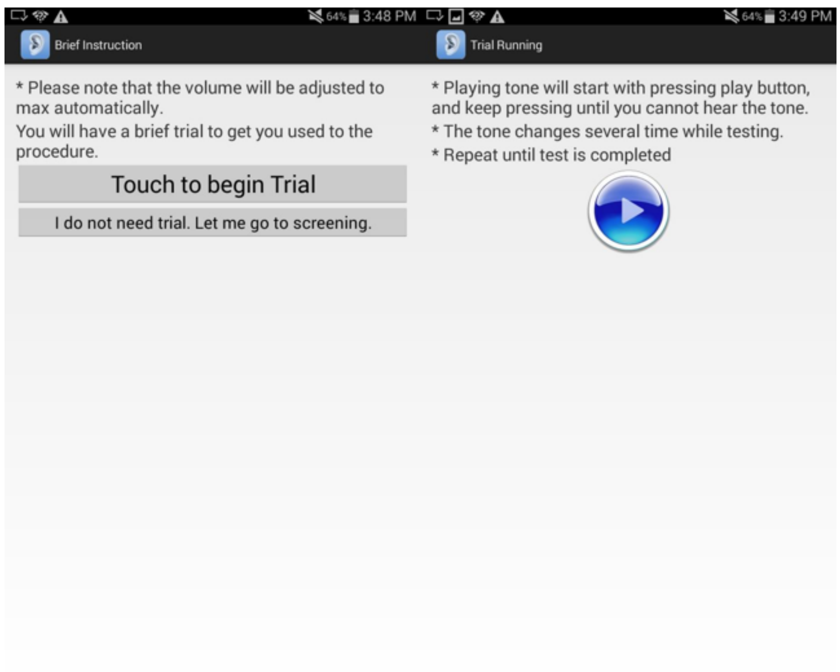
Hearing data with seven different frequencies (125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, and 8000Hz) were collected by self-administered hearing screening examinations with the hEAR mobile application. This hearing test was repeated three times per each participant (3 trials) with each frequency repeated four times per trial. Data collection was performed in the TAMU-SPH 113 lab.

There are two different methods for hearing data collection. In the first session, elderly participants learned how to conduct and use hEAR mobile application. Participants performed three trials of the self-administered hearing test by using hEAR application in the TAMU-SPH lab 113. At the second session, hearing screenings were performed in a separate appointment and different location (Texas ENT & Allergy; 1730 Birmingham Dr. College Station, TX 77845) by certified audiologists using standardized professional equipment and techniques across individual frequencies. Hearing screenings took approximately one hour at the local audiologist, Dr. Christi Madsen. Ms. Rema Lara, her technician conducted the testing while being supervised by Dr. Madsen at Texas ENT & Allergy.

When a hearing test was conducted with elderly participants in lab 113, four random frequency trial samples were given to the elderly participants before actual data collection for practicing the hEAR application. Figure 3.1 shows the hEAR application sequences on the Tablet screen.

Participants were required to press an on-screen button and keep a finger on the screen until they cannot hear anything from the headphone. 2-minute breaks were given between trials. If participants were found to have any easily-fixable ear-related issue at Texas ENT, such as an earwax blockage in the auditory canal, participants were requested to visit SPH lab and were tested with a hearing test via hEAR application again. All of the data the research team receives from Texas ENT & Allergy tests were paper-based with a random participant identifier. All data for the hEAR trials were exported to a Microsoft Excel spreadsheet and analysed using STATA ver13.0 Statistical Software (STATA Corp, College Station, TX).

Figure 3.1: The hEAR application sequence on the tablet screen



A repeated measures ANOVA model was used for statistical analysis of comparing trials. The key independent variable is hearing screening, which has seven different data points with sound pressure levels (SPL) for each ear (125Hz, 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, and 8000Hz). The dependent variables were Sound Pressure Levels (SPL) at trial 1 (a reference data from audiologists), trail 2, 3 and 4 (data from the hEAR app) with repeated 7 frequency measurements. The frequencies were used as repeated variables. By controlling for error terms, each variable interaction term was used for residual error. The repeated measures ANOVA test was conducted four times for testing hypothesis 1 and 2 [42].

The first hypothesis model expression is as below (when trial 1 dropped from the dataset):

$$\begin{aligned}\text{Y(SPL)}_{db} = f((&\text{trial}_3\text{trial}_4\text{freq}_{250Hz}\text{freq}_{500Hz}\text{freq}_{1000Hz}\text{freq}_{2000Hz}\\ &\text{freq}_{4000Hz}\text{freq}_{8000Hz})(\text{trial}_2 * \text{freq}_{250Hz})(\text{trial}_2 * \text{freq}_{500Hz})\\ &(\text{trial}_2 * \text{freq}_{1000Hz})(\text{trial}_2 * \text{freq}_{2000Hz})\\ &(\text{trial}_2 * \text{freq}_{4000Hz})(\text{trial}_2 * \text{freq}_{8000Hz}))\end{aligned} \tag{3.1}$$

The second hypothesis model expression is as below:

$$\begin{aligned}\text{Y(SPL)}_{db} = f((&\text{trial}_2\text{trial}_3\text{trial}_4\text{freq}_{250Hz}\text{freq}_{500Hz}\text{freq}_{1000Hz}\text{freq}_{2000Hz}\\ &\text{freq}_{4000Hz}\text{freq}_{8000Hz})(\text{trial}_1 * \text{freq}_{250Hz})(\text{trial}_1 * \text{freq}_{500Hz})\\ &(\text{trial}_1 * \text{freq}_{1000Hz})(\text{trial}_1 * \text{freq}_{2000Hz})\\ &(\text{trial}_1 * \text{freq}_{4000Hz})(\text{trial}_1 * \text{freq}_{8000Hz}))\end{aligned} \tag{3.2}$$

3.4 Results

To test the validity and reliability of the hEAR application, we first analyzed the summary statistic for sound pressure level that was measured by audiologists and the hEAR app. Since sound pressure level can differ depending on frequencies, we repeated the experimental trials four times on each side of the ear on each subject to investigate whether the measures of hEAR application were consistent between multiple trials and across frequencies. Table 3.1 shows the mean values of sound pressure level (SPL) across trials and over frequencies, and Figure 3.2 visualizes the mean value. The findings indicate that

SPL from audiologists show a relatively higher one than those measured by hEAR, and this pattern is consistent over frequencies and across trials. The differences between SPL from audiologists and SPL measured by hEAR are more likely to increase when the frequency is near low-end (125 Hz) or to high-end (8000 Hz). In terms of the consistency of the hEAR application, from trial 2 to trial 4, SPL measured by hEAR shows that they are relatively consistent at each level of frequency. On either side of the set of ears also shows relatively consistent test results. These findings support our hypothesis that hEAR displays consistent test results over frequencies and across trials.

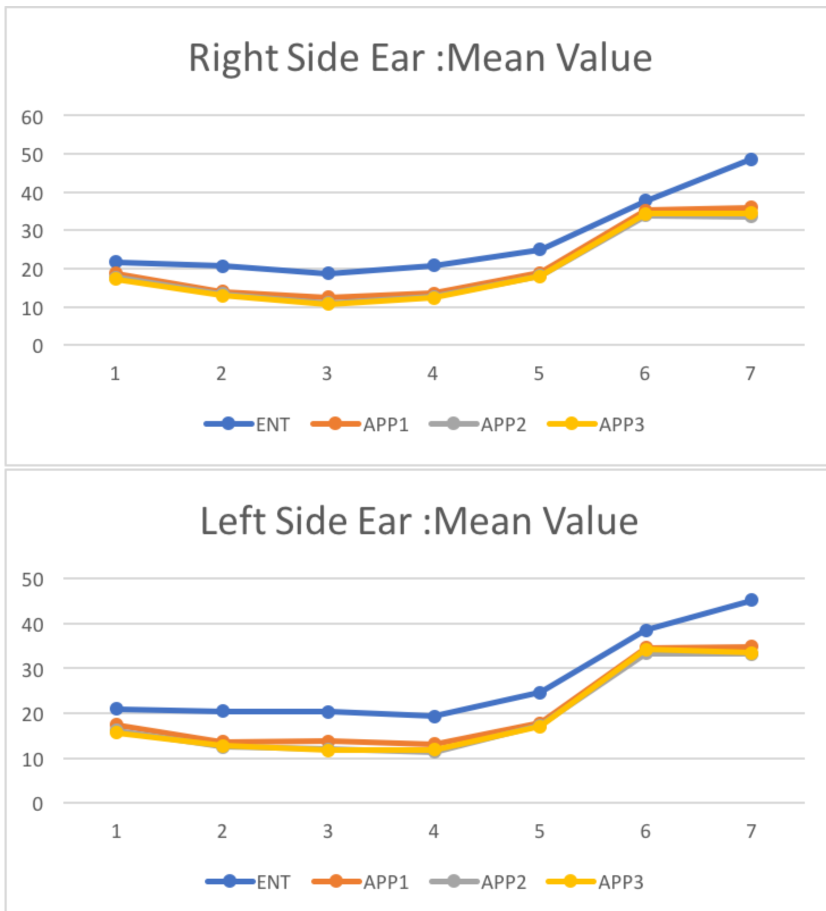
Table 3.1: Descriptive statistics for sound pressure level (SPL) over frequencies

	SPL: Right Ear				SPL: Left Ear			
Freq (Hz)	ENT	APP1	APP2	APP3	ENT	APP1	APP2	APP3
125	21.7	18.8	17.7	17.3	21.0	17.5	16.2	15.7
250	20.7	14.0	13.4	13.0	20.5	13.6	12.5	12.8
500	18.8	12.5	11.1	10.7	20.3	13.8	12.0	11.8
1000	20.8	13.6	12.6	12.4	19.3	13.2	11.4	11.9
2000	25.0	18.9	18.1	18.1	24.7	17.8	17.3	17.0
6000	37.8	35.3	33.9	34.3	38.5	34.5	33.4	34.2
8000	48.7	36.0	33.6	34.5	45.2	34.9	33.2	33.5

Note: The SPL unit is decibel (dB)

A repeated measures ANOVA model was used for analyzing whether SPL measures using hEAR are significantly consistent across trials (hEAR reliability test), and how much the SPL measures are different to the ones measured by audiologists on each subject over trials (hEAR validity test). The repeated ANOVA analysis was conducted on each ear separately.

Figure 3.2: Descriptive graph for mean value of sound pressure level (SPL) over the frequencies



3.4.1 Repeated Measures ANOVA Analysis Results for hEAR Reliability Test

Table 3.2 shows how the hEAR application repeats a consistent test SPL over time and across frequencies. We used the second trial as a baseline to compare the effect between trial 2 and 3, and between 2 and 4. As noted in Table 3.2, the findings indicate that there are no systematic differences across trials, and this result is consistent across frequencies. None of the interaction terms between frequencies and trials are statistically significant, which support our hypothesis that hEAR shows a fairly consistent test SPL measure regardless of frequency or the number of trials.

Figure 3.3 shows the visual representation of the reliability of the hEAR application. It indicates that there are no statistically significant differences among trial 2, 3, and 4, which provides a consistent evidence on the reliability of hEAR. The ANOVA result supports that the differences among trials are minimal and are not statistically significant.

3.4.2 Repeated Measures ANOVA Analysis Results for hEAR Validity Test

The validity of hEAR application was tested by comparing the SPL measure to ones measured by audiologists. Table 3.3 indicates that SPL values measured by hEAR are relatively consistent and valid when comparing to SPL values measured by audiologists regarding the right and left ear. In this model, we used the audiologist's trial as a baseline to compare and see the interaction effect between trials and frequencies. The findings show that SPL in hEAR is statistically different to SPL measured by audiologists at only the 8000 Hz data collection. When frequencies are below 8000Hz, there is no statistically different between audiologist trials and hEAR trials over time and across frequencies. This result shows that hEAR provides a valid SPL measure, and this measure is the same as SPL measured by audiologists. Figure 3.4 shows these data graphically. It indicates that the confidence interval of SPL measured by audiologist is different to the ones of SPL measured by hEAR only when the frequency is high enough to reach 8000 Hz. Interestingly, hEAR showed the same patterns of SPL measures as the audiologist's trial had. This finding supports the hypothesis $H_0 - 2$ that hEAR represents a valid hearing screening measure in an elderly population.

3.5 Discussion

In terms of the reliability of the hEAR mobile application, there is no learning curve during the three trial hearing tests among elderly participants. The repeated ANOVA test within data from hEAR app indicates that there is no statistically significant difference between each trial. As noted Figure 3.3, all three trial data points are parallel to one another. Thus, the first hypothesis ($H_0 - 1$) cannot be rejected because all p-values are greater than 0.05, except in the case of the high frequency (8000Hz) for each ear. Also, the SPL data from the hEAR mobile application is not statistically significant compared to the audiologist's hearing data based on repeated the ANOVA test result (p-value $>$0.05) for each ear. Therefore, the second hypothesis ($H_0 - 2$) also cannot be rejected because all p-values are over 0.05 except the case in the high frequency (8000Hz) for each ear. Additionally, the SPL data from the hEAR mobile application is not statistically significant compared to the audiologist's hearing data based on repeated ANOVA test result (p-value $>$0.05) for each ear. Therefore, the second hypothesis ($H_0 - 2$) also cannot be rejected because all p-values are over 0.05 except in the case of a high frequency such as (8000Hz) for each ear. Interestingly, SPL data from hEAR underestimated hearing ability when comparing their data to the SPL data from an audiologist. Generally, the mean of SPL from audiologists was lower than the hearing test result from the hEAR app because of environmental noise and better sound pressure equipment during the hearing screening test. One of the possible reasons is that the HDJ-2000 Headphone can be too sensitive. Another possible reason is that the hEAR application may place volume over the recommended level. Reducing volume levels may help to validate the hEAR application at the high-frequency level. However,

Table 3.2: The mixed ANOVA result on reliability test for the hEAR

	(1)		(2)	
	SPL: Right Ear		SPL: Left Ear	
	b	se	b	se
Trial 2 and Freq 125 baseline				
freq250	-4.800**	(1.76)	-3.750*	(1.65)
freq500	-6.300**	(1.76)	-3.500*	(1.65)
freq1000	-5.283**	(1.76)	-4.133*	(1.65)
freq2000	0.0333	(1.76)	0.467	(1.65)
freq4000	16.45**	(1.76)	17.23**	(1.65)
freq8000	17.18**	(1.76)	17.60**	(1.65)
trial3	-1.133	(1.76)	-0.900	(1.65)
trial4	-1.500	(1.76)	-1.583	(1.65)
freq250 × trial3	0.500	(2.49)	-0.0500	(2.33)
freq250 × trial4	0.433	(2.49)	0.783	(2.33)
freq500 × trial3	-0.317	(2.49)	-0.933	(2.33)
freq500 × trial4	-0.350	(2.49)	-0.450	(2.33)
freq1000 × trial3	0.200	(2.49)	-0.850	(2.33)
freq1000 × trial4	0.317	(2.49)	0.283	(2.33)
freq2000 × trial3	0.400	(2.49)	0.417	(2.33)
freq2000 × trial4	0.683	(2.49)	0.817	(2.33)
freq4000 × trial3	-0.233	(2.49)	-0.250	(2.33)
freq4000 × trial4	0.533	(2.49)	1.267	(2.33)
freq8000 × trial3	-1.333	(2.49)	-0.767	(2.33)
freq8000 × trial4	-0.0667	(2.49)	0.150	(2.33)
(constant)	18.83**	(1.69)	17.30**	(1.60)
lns1_1_1				
(constant)	1.833**	(0.14)	1.796**	(0.14)
lnsig_e				
(constant)	1.918**	(0.03)	1.855**	(0.03)
R-Squared overall	1167.27		1275.41	
N	630		630	

*P-value is notified as stars * p <0.05, ** p <0.01, *** p <0.001*

Two-tailed tests of significance

Trial 1(ENT) dropped from the model

Figure 3.3: Mixed ANOVA result graphs for the hEAR reliability test

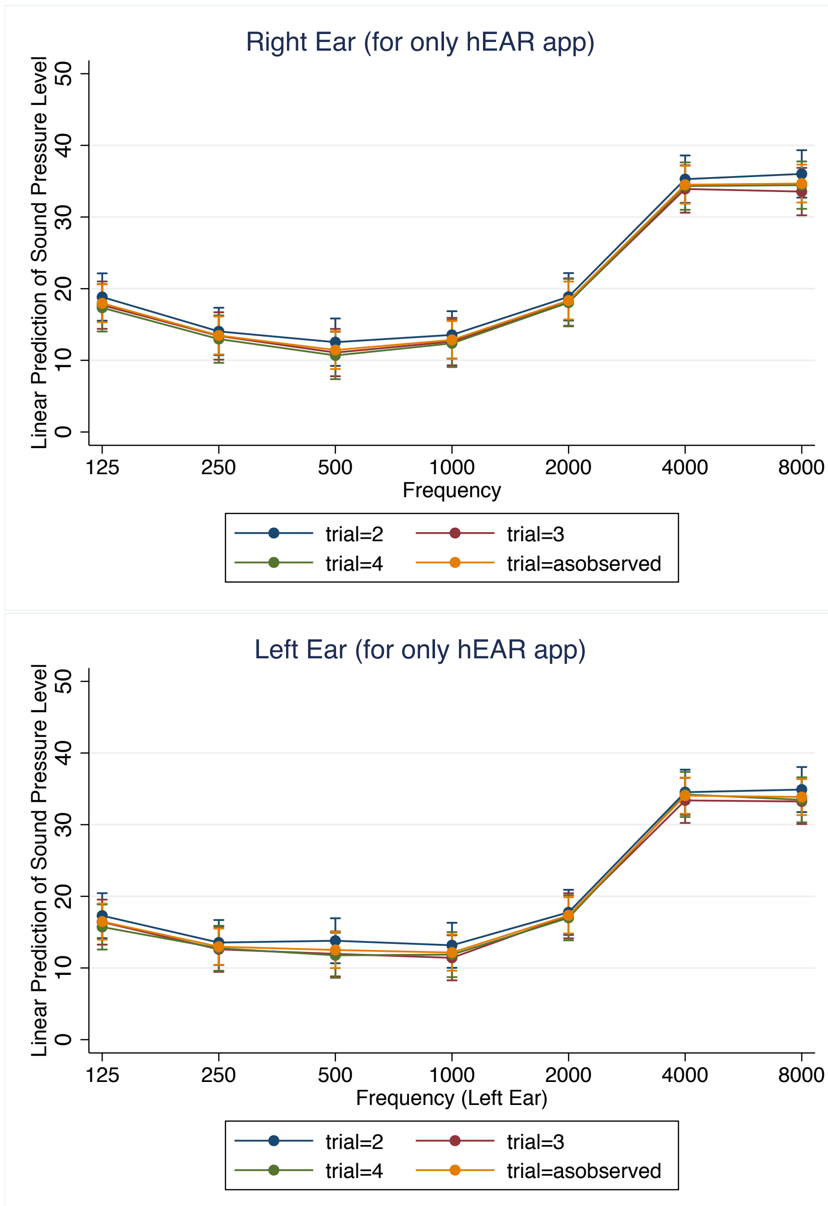
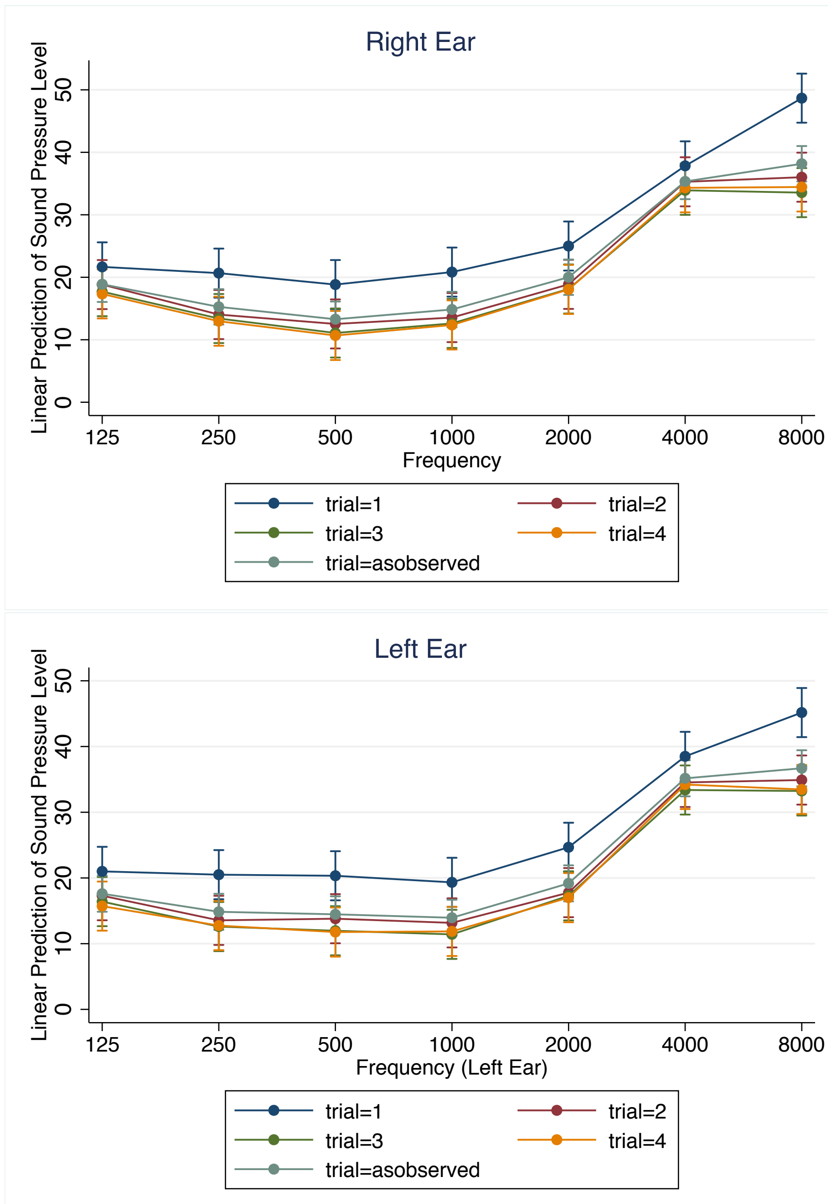


Table 3.3: The mixed ANOVA result for frequency and trial impacts on SPL

	(1)		(2)	
	SPL: Right Ear		SPL: Left Ear	
	b	se	b	se
Trial 2 and Freq 125 baseline				
250	-1.000	(2.26)	-0.500	(2.12)
500	-2.833	(2.26)	-0.667	(2.12)
1000	-0.833	(2.26)	-1.667	(2.12)
2000	3.333	(2.26)	3.667+	(2.12)
4000	16.17**	(2.26)	17.50**	(2.12)
8000	27.00**	(2.26)	24.17**	(2.12)
trial=2	-2.833	(2.26)	-3.700+	(2.12)
trial=3	-3.967+	(2.26)	-4.600*	(2.12)
trial=4	-4.333+	(2.26)	-5.283*	(2.12)
250 × trial=2	-3.800	(3.20)	-3.250	(2.99)
250 × trial=3	-3.300	(3.20)	-3.300	(2.99)
250 × trial=4	-3.367	(3.20)	-2.467	(2.99)
500 × trial=2	-3.467	(3.20)	-2.833	(2.99)
500 × trial=3	-3.783	(3.20)	-3.767	(2.99)
500 × trial=4	-3.817	(3.20)	-3.283	(2.99)
1000 × trial=2	-4.450	(3.20)	-2.467	(2.99)
1000 × trial=3	-4.250	(3.20)	-3.317	(2.99)
1000 × trial=4	-4.133	(3.20)	-2.183	(2.99)
2000 × trial=2	-3.300	(3.20)	-3.200	(2.99)
2000 × trial=3	-2.900	(3.20)	-2.783	(2.99)
2000 × trial=4	-2.617	(3.20)	-2.383	(2.99)
4000 × trial=2	0.283	(3.20)	-0.267	(2.99)
4000 × trial=3	0.0500	(3.20)	-0.517	(2.99)
4000 × trial=4	0.817	(3.20)	1.000	(2.99)
8000 × trial=2	-9.817**	(3.20)	-6.567*	(2.99)
8000 × trial=3	-11.15**	(3.20)	-7.333*	(2.99)
8000 × trial=4	-9.883**	(3.20)	-6.417*	(2.99)
(constant)	21.67**	(2.00)	21.00**	(1.91)
lns1_1_1				
(constant)	1.887**	(0.14)	1.867**	(0.14)
lnsig_e				
(constant)	2.171**	(0.03)	2.104**	(0.03)
R-Squared overall				
N	840		840	

*P-value is notified as stars * p <0.05, ** p <0.01, *** p <0.001;*
Two-tailed tests of significance

Figure 3.4: Mixed ANOVA result graphs for the hEAR validity test



audiologists and researchers generally use better ear hearing level (BEHL) as the standard for detecting hearing loss, which only includes 500Hz, 1000Hz, 2000Hz, 4000Hz when they test for hearing loss [51]. Therefore, results of this data collection indicate that the current iteration of the hEAR application, when paired with the Pioneer HDJ-2000 headphones, can be useful in clinical settings for a hearing screening of an elderly individual.

3.5.1 Limitations

Environmental noise may not be completely controlled during the hEAR application hearing test. The lab 113 was a quiet room, but the outside noise may not be perfectly controlled during the hearing test as was the case with the audiologist data collection. It might affect the accuracy of hearing data collection by altering the participant's response to not hearing the presented tone. As 30 participants were recruited in this hearing study, the small number of observations can limit the statistical power. In addition to that, most of the participants were relatively healthy and had less hearing loss problems compared to their age group. Therefore, there were no participants who had severe or profound hearing impairment. Also, a total of four participants (3 males and 1 female) were retested because of earwax-blocked ear drum. This was discovered during their data collection procedure at Texas ENT & Allergy. They visited their personal physicians to remove the earwax, and then came back to conduct hearing screening examination with the audiologists at Texas ENT and hEAR at SPH 113 lab.

Although most of the participants were very healthy, some participants found it difficult to hold their finger on the application screen because of Parkinson's Disease or essential tremor. Elderly users may slip their finger from the application screen as a mistake while they are conducing a hearing test via the hEAR application. However, internal algorithms for detection of false positives automatically re-administer test frequencies thought to be false positive responses. Results of the data collection shown in Section 3.4.1 and

3.4.2 indicate that even for those individuals, the data collection produced quality results.

3.5.2 Strengths

The average hearing test time was less than 5 minutes in each trial although hearing test time highly depends on elderly participant's hearing ability. One of the strengths of the hEAR application is accessibility for conducting automated self-administrated hearing tests. Elderly participants can easily use the hEAR application without any help from specialists. They only need to follow the application's on-screen instructions. Also, elderly participants can save time and money by not having to schedule and attend audiological appointments. If an automated application such as the hEAR application were available to primary care physicians, it would simply remove part of the annual check-up and the patient would be able to produce quality hearing screening results for potential early diagnosis of hearing impairment among the elderly population.

3.6 Conclusion

The SPL data from the hEAR mobile application has no detectable difference from one from an audiologist based on the repeated ANOVA statistical results across all frequencies except 8000 Hz. Also, the hearing data from the hEAR application is reliable because there is no significant difference across trials for the hEAR application. Although it needs to be adapted to elderly participants with severe and profound hearing impairment in order to provide a proper evaluation of participants with different hearing conditions, these findings indicate that hEAR is a valid and reliable hearing screening data collection application for elderly participants.

The hEAR mobile application will be helpful for determining their hearing health status by providing an automated self-administered hearing test in their home or primary care Physician's office. For further studies, if the hEAR application could automatically produce diagnostic results on whether participants have hearing loss at the level of hearing impairment (No hearing loss, Mild, moderate, severe and profound hearing loss), it would be more far more helpful in understanding their hearing health status.

4. AN EXPERIMENTAL STUDY ON THE EFFECT OF HEARING LOSS ON QUALITY OF LIFE AMONG THE ELDERLY

4.1 Overview

Age-related hearing loss (ARHL), which is more accurately referred to clinically as *presbycusis*, presbycusis, is the one of most prevalent condition of decreasing hearing performance among elderly individuals in United States [52, 1]. There are many different veins of research relating hearing impairment among the elderly population aimed at identifying a comprehensive understanding in terms of physical, mental, fall rate and health-related quality of life [44]. Based on the previous literature review, only 20% of elderly people with hearing loss recognize that they need to see a physician. Hearing loss can affect their awareness of their environment, speech understanding, and hearing at high frequencies [7]. Also, ARHL can lead elderly individuals into fatigue by increasing the cognitive load required to engage in and recognize conversational patterns and different environmental situations [53].

The comprehensive understanding of hearing loss related with HRQOL can help the elderly population with the improvement of their overall well-being and quality-of-life by early detection of hearing impairment and treating hearing loss with an appropriate method.

4.2 Hypothesis

Based on the literature review and experimental settings, this study aims to test the following null hypotheses:

$H_0 - 1$: There is no statistically significant relationship between hearing loss and health-related quality of life.

$H_0 - 2$: There is no statistically significant relationship between hearing loss and physical related quality of life.

$H_0 - 3$: There is no statistically significant relationship between hearing loss and mental related quality of life.

4.3 Methods

The existing evidence indicates that hearing impairment is associated with HRQOL in the elderly population. One of the most commonly used mechanisms to assess this situation is the self-administered 36-item Short-Form Health Survey (SF-36), which includes an assessment of the physical and mental health-related qualities of life [29]. Hearing impairment is strongly associated with the decreasing ability of physical function in the self-reported physical capacity survey with objective audiometry [3].Another common data collection mechanism is the short-term battery test (SPPB) score as this can be representative of physical capacities in elderly populations by taking balance, walking and lower-limb strength tests. Hearing impairment is negatively associated with SPPB scores in older people in the United States [54]. Also, lower SPPB scores are related to high fall rates among the elderly [17]. Additionally, cognitive functional abilities are associated with the level of hearing impairment including mild, moderate, and severe levels. Hearing loss is independently related with declining central auditory function and short & long-term memory abilities [55].The MMSE scores of mini-mental state examination (MMSE) are negatively associated with ARHL [56].

The measurement of health-related quality of life (HRQOL) index of SF-36 ranges from 0 to 100. In our sample, most participants responded close to 80-90, so the right skewed distribution of HRQOL index makes it difficult to use a linear model (e.g OLS model). It could not satisfy the normality assumption of a linear model with a small N of 30 observations. Since the 0-100 scale can be transformed to a 'Letter Grade (A-E), the researcher used the letter grade transformed scale and employed a non-linear model rather than an ordered logistic model, to investigate whether ‘better ear hearing threshold level (BEHL)‘ is associated with categorical scales of ‘quality of life‘ [57]. The letter grade transformation is shown in Table 4.1

Table 4.1: Quality of life grade score

Grade	Scoring Range
A (5)	90-100
B (4)	80-90
C (3)	70-80
D (2)	60-70
E (1)	below than 60

The following items show the details of the quality of life sub-group variables: 1)total quality of life score, 2) physical functioning, 3) role limitation due to physical health, 4) role limitation due to emotional problem, 5) energy/fatigue, 6) emotional well-being, 7) social functioning, 8)pain, 9) general health, 10) physical component summary score (PCS), and 11) mental component summary score (MCS) [58]. Each quality of life score from the subcategories was correlated with the total quality of life score except for the role of emotional and social function subcategories because two components of the quality of life score were scored to almost 100 points. Only one or two participants from the thirty participants did not receive 100 points, therefore, there was no variation across participants.

The independent variables are ‘better ear hearing threshold level (BEHL)‘ and ‘5-grade BEHL’. In air conduction, pure-tone hearing thresholds were measured at the frequencies of 125, 250, 500, 1000, 2000, 4000, and 8000 Hz, followed by International Organization for Standardization (ISO) 8253-1 [59]. Previous literature defines the BEHL as the average of the pure-tone hearing thresholds at 500, 1000, 2000, and 4000 Hz, and then choosing the ear that shows better results. A high level of BEHL indicates the more likelihood of hearing loss [15].

BEHL can be categorized by 5 grades as Table 4.2 [60]. In our sample, all participants fell into categories 1-3. A higher grade indicates a more severe hearing loss. Major control variables, such as male (sex), age, the level of education and Body Mass Index (BMI) are included in the model. Table 4.3 shows the summary statistics of the dependent and independent variables.

Table 4.2: BEHL grade score

Grade	Scoring Range
No hearing loss	0-25
Mild loss	25-40
Moderate loss	40-60
Severe loss	60-80
Profound	over 80

Ordered logistic regression was used for analyzing the quality of life data sets after transforming different types of a dependent variables into a categorical variable because most of the dependent variables related to the quality of life score were not normal.

4.4 Results

4.4.1 The Effect of BEHL on Quality of Life

The hearing data were collected from the Texas ENT & Allergy and hEAR mobile application. The data consisted of 14 continuous variables with SPL for 7 right and 7 left. HRQOL data were collected from SF-36 through a continuous variable. However, the dependent variable was not normal because the data were skewed on the right side. As an

Table 4.3: Summary statistics for variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Dependent Variables (ranged 0-100)					
Total_quality of Life	30	85.981	9.682	57.361	97.222
Physical functioning	30	84.667	19.429	20	100
Role limitations due to physical health	30	91.667	18.952	25	100
Role limitations due to emotional problems	30	98.889	6.086	66.667	100
Energy/fatigue	30	77.833	12.573	45	100
Emotional well-being	30	87.867	9.066	72	100
Social functioning	30	97.917	5.764	75	100
Pain	30	84.833	14.999	45	100
General health	30	81.667	16.206	30	100
PCS	30	85.302	14.409	38.81	100
MCS	30	88.798	5.909	77.143	100
Dependent Variables (Grade: 1-5)					
Total_quality of Life	30	4.033	1.066	1	5
Physical functioning	30	3.9	1.269	1	5
Role limitations due to physical health	30	4.4	1.303	1	5
Role limitations due to emotional problems	30	4.9	.548	2	5
Energy/fatigue	30	3.067	1.112	1	5
Emotional well-being	30	4.267	.868	3	5
Social functioning	30	4.833	.461	3	5
Pain	30	3.6	1.303	1	5
General health	30	3.5	1.306	1	5
PCS (Grade)	30	4.033	1.098	1	5
MCS (Grade)	30	4.333	.606	3	5
Independent Variables					
BEHL (0-100)	30	23	10.285	10	43.75
BEHL 5 grade (1-5)	30	1.433	.626	1	3
Control Variables					
Male	30	.5	.509	0	1
Age	30	67.933	5.942	60	79
Education (grade)	30	4.8	.484	3	5
BMI	30	28.4	6.06	20.5	47.9

alternative method to the Ordinary Least Squared linear model analysis, the letter grade transformation was applied to the quality-of-life score to conduct the ordered-logistic analysis. In addition, 5 levels of hearing health stages categorized hearing data. After the transformation of the dependent variable, ordered logistic analyses were performed.

In the non-linear model, using the letter grade scale on the quality of life index, total HRQOL, physical, energy, emotional, and general health are all negatively associated with hearing loss. (Table 4.4, 4.5, and 4.6). Table 4.4 indicates that BEHL was negatively associated with the total quality of life score. Also, hearing impairment was related to the physical and mental quality of life when controlling for sex, age, education level and BMI. Interestingly, BMI is one of the key predicting factors for physically and mentally health quality-of-life. Age was also significantly associated with mental HRQOL. In this model, role limitations due to emotional problems were dropped because there were no variations across participants: 29 out of 30 participants answered 100 whereas only 1 participant answered 66. The physical, energy/fatigue, emotional and general HRQOL components can be negatively affected by BEHL (see Table 4.5). The BMI was significantly associated with general health statues from SF-36 component. BEHL influences emotional health status among elderly participants. Based on the statistical results, the quality of life based on the social and pain component did not show a significant relationship with BEHL.(see Table 4.6).

Table 4.4: The impact of hearing level (BEHL) on quality of life

	(1) Total QOL(Grade)		(2) PCS		(3) MCS	
	b	se	b	se	b	se
BEHL	-0.138**	(0.05)	-0.125**	(0.04)	-0.215**	(0.07)
Male	0.483	(0.88)	0.784	(0.87)	-1.171	(1.08)
Age	-0.0159	(0.07)	0.00293	(0.06)	0.232*	(0.10)
Education	0.786	(0.78)	0.516	(0.78)	0.359	(1.09)
BMI	-0.100	(0.08)	-0.123+	(0.07)	-0.171+	(0.10)
N	30		30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, ordered logit model
All dependent variables transformed as letter grade (A to E)
Constants not reported here

Table 4.5: The impact of hearing level (BEHL) on quality of life grade

	(1) Physical (Grade)		(2) Role physical (Grade)		(3) Energy (Grade)	
	b	se	b	se	b	se
BEHL	-0.101*	(0.04)	-0.105+	(0.06)	-0.0737*	(0.04)
Male	1.664+	(0.87)	-1.041	(1.30)	-0.593	(0.78)
Age	-0.0291	(0.06)	0.0676	(0.09)	0.0790	(0.07)
Education	0.905	(0.74)	-0.255	(1.44)	0.733	(0.77)
BMI	-0.0826	(0.08)	-0.164	(0.11)	-0.0712	(0.07)
N	30		30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, ordered logit model
all variables transformed as letter grade (A to E)
The one DV: Role limitations due to emotional problems (Grade) dropped
constants not reported here

Table 4.6: The impact of hearing level (BEHL) on quality of life grade (2)

	(5) Emotional		(6) Social		(7) Pain		(8) General Health	
	b	se	b	se	b	se	b	se
BEHL	-0.165**	(0.06)	-0.0734	(0.06)	-0.0247	(0.04)	-0.0876*	(0.04)
Male	0.0473	(1.01)	-0.0978	(1.39)	0.198	(0.78)	-0.347	(0.79)
Age	0.239*	(0.10)	0.0548	(0.11)	0.101	(0.07)	-0.0188	(0.06)
Education	-1.311	(1.30)	-0.337	(1.58)	0.724	(0.78)	-0.0427	(0.77)
BMI	0.00185	(0.09)	-0.126	(0.11)	0.00595	(0.07)	-0.165*	(0.07)
N	30		30		30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, ordered logit model
all variables transformed as letter grade (A to E)
constants not reported here

4.4.2 The Effect of 5-grade BEHL on Quality of Life

When BEHL is changed to the 5-grade index from continuous variables, the results were consistent across subcategories of the quality of life (see Table 4.7, 4.8, and 4.9). The relationship between hearing impairment and quality of life was almost similar when using BEHL or BEHL with the 5-grade index as a degree of no hearing loss, mild and moderate hearing loss. Interestingly, Grade BEHL was negatively associated with physical functioning and not significantly associated with energy/fatigue component compared to table 4.6. (see Table 4.9)

Table 4.7: The impact of 5-grade hearing level (BEHL) on quality of life

	(1) Total QOL(Grade)		(2) PCS		(3) MCS	
	b	se	b	se	b	se
BEHL 5 grade	-2.194**	(0.74)	-2.215**	(0.72)	-2.213**	(0.85)
Male	0.546	(0.87)	1.000	(0.89)	-0.981	(1.02)
Age	-0.0392	(0.06)	-0.0139	(0.06)	0.127	(0.08)
Education	0.900	(0.79)	0.615	(0.79)	0.492	(0.97)
BMI	-0.0847	(0.08)	-0.113	(0.07)	-0.133	(0.09)
N	30		30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, ordered logit model

All dependent variables transformed as letter grade (A to E)

Constants not reported here

Table 4.8: The impact of 5-grade hearing level (BEHL) on quality of life grade

	(1) Physical(Grade)		(2) Role physical(Grade)		(3) Energy (Grade)	
	b	se	b	se	b	se
BEHL 5 grade	-1.534*	(0.65)	-1.315	(0.91)	-0.950	(0.61)
Male	1.819*	(0.91)	-0.811	(1.30)	-0.532	(0.79)
Age	-0.0523	(0.06)	0.0519	(0.09)	0.0577	(0.06)
Education	0.935	(0.75)	-0.305	(1.44)	0.759	(0.77)
BMI	-0.0768	(0.08)	-0.140	(0.11)	-0.0714	(0.07)
N	30		30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, ordered logit model

all variables transformed as letter grade (A to E)

The one DV: Role limitations due to emotional problems (Grade) dropped

constants not reported here

Table 4.9: The Impact of 5-grade hearing level (BEHL) on quality of life grade (2)

	(5) Emotional		(6) Social		(7) Pain		(8) General Health	
	b	se	b	se	b	se	b	se
BEHL 5 grade	-1.844*	(0.82)	-1.174	(1.03)	-0.459	(0.60)	-1.343*	(0.63)
Male	-0.154	(0.94)	0.146	(1.50)	0.214	(0.78)	-0.369	(0.78)
Age	0.175*	(0.09)	0.0476	(0.12)	0.0978	(0.07)	-0.0286	(0.06)
Education	-1.085	(1.33)	-0.347	(1.57)	0.760	(0.79)	0.00881	(0.77)
BMI	-0.00473	(0.09)	-0.118	(0.11)	0.00863	(0.07)	-0.157*	(0.07)
N	30		30		30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, ordered logit model
all variables transformed as letter grade (A to E)
The one DV: Role limitations due to emotional problems (Grade) dropped
constants not reported here

4.5 Discussion

Overall, results indicated that hearing loss was significantly associated with health-related quality of life (HRQOL) scores when using the SF-36 that included physical, energy and fatigue, emotional and general health as sub-categories of HRQOL. The results supported the evidence of previous hearing loss studies. According to the quality of life studies, hearing impairment was strongly associated with HRQOL by decreasing both mental and physical ability in the elderly [2]. Although elderly participants with severe hearing loss were excluded from data collection, results indicate the negative relationship between hearing loss and HRQOL. In addition to that, hearing loss can negatively affect speech understanding and communication, which results in emotional and mental problems among elderly [61]. The findings of this study showed that hearing loss can reduce energy in elderly daily life. Hearing loss can be associated with the physical and mental quality of life. The findings supported that hearing impairment has a strong relationship with physical and mental component scores from SF-36. BMI is one of the key predictors of the physical and general health of QOL. Age was also associated with the mental health of QOL.

4.5.1 Limitations

The quality of life data were not a normal distribution. After using several transformation methods, such as log and box-cox transformation, dependent variables still had non-normal distribution because of the characteristics of the data observations. The participants were healthy compared with other elderly because someone have physical and hearing problem were excluded from recruitment for the study. Thus, the quality of life score was left skewed because most of participants received high score from SF-36.

The small sample size of 30 participants for this study is also a limitation. To analyze the relationship between hearing impairment and HRQOL, a larger sample size would be needed to increase the statistical power. Also, severe and profound hearing loss participants were excluded from this study due to the issue of safety that was involved for the physical activities needed for the experiment. The study lacks evidence showing the various relationships between serious hearing loss levels and HRQOL, and further experimentation is needed at a larger scale to do so.

4.5.2 Strengths

The results of this study strongly support the evidence of existing hearing loss studies that displayed a relationship between HRQOL based on hearing screening tests from audiologists. Most studies used self-reported hearing surveys due to the cost- and time-saving benefits of such surveys. This study conducted hearing screening tests with certified audiologists to ensure the accuracy of the levels of hearing impairment. This helps to verify the relationship of HRQOL and hearing loss. Even though our data did not include the elderly with severe and profound hearing loss, the results indicated that mild hearing loss is still associated with HRQOL.

4.6 Conclusions

The study has shown that age-related mild and moderate hearing loss is negatively associated with HRQOL with categories such as physical, emotional, and general health using SF-36. Further research is needed that includes more participants for increased statistical power, and diversity among participants in terms of mild to severe/profound hearing loss.

5. THE IMPACT OF HEARING LOSS ON THE PHYSICAL CAPABILITY, COGNITIVE ABILITIES, AND RISK OF FALLS AMONG THE ELDERLY

5.1 Overview

For the elderly population, hearing loss is associated with various physical and cognitive abilities. Adjusting for age and cardiovascular disease history, hearing impairment can negatively affect physical functional ability among the elderly [3]. Among basic physical abilities, balance capacity is a critical sub-category for living daily life. Existing literature provides evidence that losing balance among older adults is a key problem that results in an increased risk for falls during their daily life [62].

Interestingly, hearing loss is associated with decreased balance capacities [63]. Since physical abilities can determine health-related quality of life (HRQOL) by increasing the likelihood of injuries in their daily life [27], the relationship between hearing loss and balance capacity should be studied. This chapter examines how hearing loss is associated with balance ability by using a force plate with three different foot positions. In addition, this study also seeks to test the general physical abilities among the elderly, using a short term battery test (SPPB), timed up and go (TUG) test, maximum leg length test, hand grip strength, and perceived activities daily living scale (ADL) in order to determine the linkage between hearing loss and physical abilities [16].

In addition to balance and quality-of-life linkages, hearing loss has been shown to increase the risk of falls among elderly individuals [15]. Hearing loss decreases mobility, increasing the chance of falling, and decreases basic physical functioning. This research looks to examine the linkage between hearing loss and a risk of fall using participants' perceived evaluation on their past fall experience. The findings will provide a comprehensive understanding of the relationship between hearing ability and various body abilities among older adults.

Literature also indicates that elderly individuals with hearing impairment are more likely to have cognitive ability declines [64]. Previous studies provide a strong evidence of the relationship between hearing impairment and declining cognitive ability in the elderly population [5]. Due to that particular relationship, hearing loss can be a predictor of potential cognitive diseases such as dementia [65]. It is to that end that this study examines how hearing loss is associated with cognitive abilities using two tests – mini mental state examination and trail making test.

5.2 Hypotheses

This study aims to find the linkage between hearing loss and physical/cognitive abilities. Researchers conducted three physical experiments and two cognitive experiments with 30 elderly participants. This study seeks to test the following three null hypotheses:

$H_0 - 1$: There is no statistically significant association between hearing loss and physical capabilities.

$H_0 - 2$: There is no statistically significant relationship between hearing loss and cognitive abilities.

$H_0 - 3$: There is no statistically significant relationship between hearing loss and a risk of fall.

5.3 Methods

The details in the experimental procedure were described in Chapter 2. The balance data were collected using an AMTI force plate with three different foot positions. For the AMTI force plate data analysis, two axes including x, y were used for balance data analysis. Each axis had 5000 data points after data cleaning due to the fact that balance data were calculated for 10 seconds with 500Hz/sec. Each data set including moment x- and y- axis was applied 4th order Butterworth low pass filter with cutting off 5000Hz frequency [66]. After that, based on the collected COP, three different variables were measured and calculated such as the average of mediolateral velocity, anteroposterior velocity (mm/s) and velocity moment (in term of x- and y-axis on each three types of foot positions – side by side, semi-tandem and tandem position) [15]. ANOVA analysis for the differences between groups (no hearing loss, mild loss and moderate groups) was conducted based on COP in side by side, semi-tandem, tandem, and activities associated with daily living scale as well as fall injury experience.

5.4 Results

The total of 30 participants were able to finish all physical and cognitive tests without any errors. Table 5.1 shows the summary statistics of hearing loss, physical tests, cognitive test, perceived assessment on fall experience and activities on the daily living scale. In terms of balance tests, the mean COP from mediolateral, anteroposterior velocity (mm/s) and velocity moment (mm^2/s) between side-by-side and semi-tandem foot position are similar. Results indicate that participants put more effort into keeping their balance on the force plate with the tandem foot position during the 10 second period. Many different types of physical tests were conducted during the experiments of SSPB, TUG, the maximum leg length test, and handgrip strength test. Mini mental state examination and trail making tests were also conducted to check elderly participant's cognitive abilities. The mean of the total SPPB score was 11.2 points out of 12 points. All participants received full scores for the SPPB balance test which means that all participants kept their balance for the required 10 seconds with three different foot positions. The SPPB chair stand score was score among elderly participants.

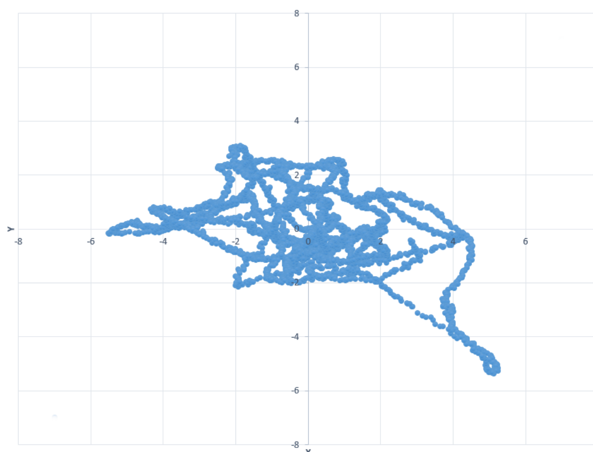
Figure 5.1, 5.2 and 5.3 display an example of a participantâĂŹs position in terms

Table 5.1: Descriptive statistics for key variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Hearing Loss Threshold (IV)					
better ear hearing threshold level (BEHL)	30	23	10.285	10	43.75
BEHL 5-grade	30	1.433	.626	1	3
Physical Ability Test					
Balance Test: COP in side by side stance					
Mediolateral velocity	30	23.77	5.59	18.50	41.92
Anteroposterior velocity	30	22.78	6.26	18.71	51.38
Velocity moment	30	39.10	38.63	5.18	187.36
Balance Test: COP in Semi-tandem					
Mediolateral velocity	30	23.63	5.59	18.46	38.37
Anteroposterior velocity	30	23.05	5.82	18.64	49.91
Velocity moment	30	38.32	29.39	7.71	126.94
Balance Test: COP in Tandem					
Mediolateral velocity	30	31.98	11.82	21.08	67.51
Anteroposterior velocity	30	32.62	7.75	22.42	48.47
Velocity moment	30	135.5	130.4	23.95	481.7
SPPB test					
Total Score of SPPB	30	11.2	.961	9	12
SPPB Balance Score	30	4	0	4	4
SPPB Gait Speed Score	30	3.867	.346	3	4
SPPB Chair Stand Score	30	3.333	.758	2	4
SPPB Gait Speed Average Time	30	3.1	.427	2.4	4.01
SPPB Chair Stand Time	30	11.39	2.29	7.56	16.55
Tug Test					
Tug Test Average Time	30	8.95	1.1	6.74	11.57
Maximum Leg Length Test					
Leg Test Average Distance	30	31.63	6.21	20.05	47.3
Hand Grip Test					
Hand Grip Average Strength	30	35.42	10.65	20	54.6
Activities Daily Living Scale					
ADL	30	5.96	.18	5	6
IADL					
Male	15	5	0	5	5
Female	15	8	0	8	8
Cognitive Ability Test					
Mini Mental State Examination	30	28.86	1.57	25	30
Trail Making Test					
Trail Making Test (part1)	30	26.44	6.25	16.72	40.98
Trail Making Test (part2)	30	58.78	26.64	27.84	175.53
Fall Injury Experience					
At least one fall per month (Y=1)	30	.13	.34	0	1
At least one fall per year (Y=1)	30	.4	.49	0	1
At least one injurious fall per year (Y=1)	30	.06	.25	0	1

of side-by-side, semi-tandem, and tandem foot positions. They also show an average performance on a force plate. The graphs display the traces of a participantâĂŹs moving pattern: COP was frequently changed based on the x- and y-axis. As noted in the figure, side by side (Figure 5.1) and semi-tandem (Figure 5.2) positions showed less frequent change, where the tandem (Figure 5.3) foot position frequently changed on the basis of the center point.

Figure 5.1: Balance test trace at side-by-side



From ANOVA results displayed on table 5.2, COP results showed that there are no statistically significant differences among BEHL groups that include no hearing loss, mild, and moderate hearing loss. Also, most participants were scored this complete points in terms of ADL and IADL except for only one participant. There was no variance between the ADL and IADL result.

To increase statistical power of analysis for ANOVA test, a binary category for hearing loss is used: one group has no hearing loss, and the other group has any level of hearing loss (from mild to moderate). Table 5.3 shows that COP result with tandem foot

Figure 5.2: Balance test trace at semi-tandem

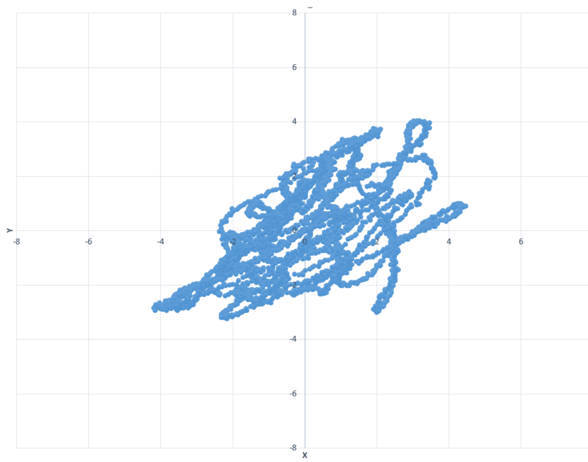


Figure 5.3: Balance test trace at tandem

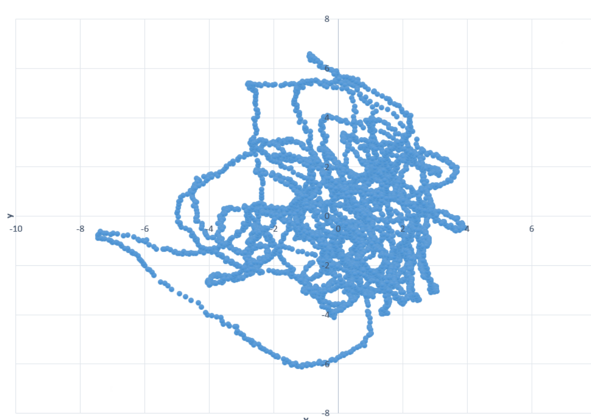


Table 5.2: Descriptive analysis and ANOVA results on COP movement and falls according to different BEHL grades

BEHL Grade	No Hearing Loss (1) (N=19)		Mild Loss (2) (N=9)		Moderate (3) (N=2)		ANOVA
	Mean	SD	Mean	SD	Mean	SD	p-value
COP in side by side							
Mediolateral velocity	24.04	6.20	23.46	5.10	22.64	1.67	0.93
Anteroposterior velocity	23.11	7.61	22.56	3.21	20.58	0.34	0.86
Velocity moment	40.45	44.71	37.96	29.68	31.37	8.99	0.94
COP in Semi-tandem							
Mediolateral velocity	22.67	5.01	25.66	7.06	23.70	0.30	0.43
Anteroposterior velocity	22.80	6.83	23.78	4.09	22.15	0.54	0.9
Velocity moment	34.05	30.92	45.73	29.38	45.38	1.92	0.59
COP in Tandem							
Mediolateral velocity	28.78	8.38	38.89	15.79	31.28	12.84	0.1
Anteroposterior velocity	30.44	6.89	36.17	6.98	37.32	15.76	0.12
Velocity moment	103.28	107.04	194.33	160.3	177.06	165.19	0.2
Activities Daily Living Scale							
ADL	5.947	.229	6	0	6	0	0.76
IADL							
Male	5	0	5	0	5	0	N/A
Female	8	0	8	0	8	0	N/A
Fall Injury Experience	n	%	n	%	n	%	
At least one fall per month	2	50	2	50	0	0	0.61
At least one fall per year	8	66.6	3	25	1	8.3	0.87
At least one injurious fall	2	100	0	0	0	0	0.56

Note:Among 5 grade of BEHL, our sample had only 3 categories - no loss, mild and moderate loss
None of COPs and falls were not significantly different between BEHL groups

position shows significant differences between the groups. It indicates that hearing loss significantly influences balance when it comes to the tandem position.

Table 5.3: Descriptive analysis and ANOVA results on COP movement and falls according to binary BEHL grade

BEHL Grade	No Hearing Loss (0) (N=19)		Any types of Hearing Loss (1) (N=11)		ANOVA
	Mean	SD	Mean	SD	p-value
COP in side by side					
Mediolateral velocity	24.047	6.204	23.312	4.61	0.73
Anteroposterior velocity	23.115	7.619	22.208	2.985	0.70
Velocity moment	40.45	44.711	36.764	26.831	0.80
COP in Semi-tandem					
Mediolateral velocity	22.67	5.014	25.31	6.37	0.21
Anteroposterior velocity	22.809	6.835	23.487	3.721	0.76
Velocity moment	34.059	30.917	45.672	26.286	0.30
COP in Tandem					
Mediolateral velocity	28.784	8.381	37.508	15.02	0.04
Anteroposterior velocity	30.443	6.89	36.383	8.003	0.04
Velocity moment	103.288	107.046	191.195	152.758	0.07
Activities Daily Living Scale					
ADL	5.947	.229	6	0	0.45
IADL					
Male	5	0	5	0	N/A
Female	8	0	8	0	N/A
Fall Injury Experience	n	%	n	%	
At least one fall per month	2	50	2	50	0.56
At least one fall per year	8	66.6	4	33.3	0.76
At least one injurious fall	2	100	0	0	0.28

Note: Among 5 grade of BEHL, our sample had only 3 categories - no loss, mild and moderate loss.
To increase statistical power, the binary category (hearing loss exist=1, otherwise 0) is used in this table
None of COPs and falls were not significantly different between BEHL groups

Table 5.4 show the impacts of hearing impairment on fall experience. There is no statistically significant relationship between the level of hearing loss and fall experience when adjusting with all related control variables, including male, age, education, BMI and COP moment. Given the fact that only one injury existed across all fall experience reports, no relationship was found between falling and hearing loss.

Table 5.4: The impact of hearing level (BEHL) grade on fall

	(1)		(2)	
	At least one fall per month		At least one fall per year	
	b	se	b	se
BEHL 5 grade	0.979	(1.04)	0.401	(0.81)
Male	-0.918	(1.56)	0.601	(1.08)
Age	-0.00534	(0.12)	-0.0958	(0.09)
Education	-0.181	(1.36)	0.329	(1.24)
BMI	0.0666	(0.13)	0.0617	(0.11)
COP moment (side by side)	0.0120	(0.05)	0.0418	(0.03)
COP moment (semi-tendem)	-0.0298	(0.06)	-0.0533	(0.04)
COP moment (tendem)	-0.00916	(0.01)	0.00274	(0.00)
(constant)	-2.163	(12.64)	1.808	(10.15)
R-Squared overall	0.15		0.12	
N	30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, logit model

Given no variance in ‘one injurious fall‘, no findings has been found

Most of the elderly participants received 28 points from the MMSE cognitive test which means that all participants had no issue of cognitive impairment following the MMSE scoring standard which is generally below 25 points [67]. The multivariate linear regression model was used to analyse the relationship between hearing impairment and physical/cognitive abilities. In table 5.5, the SPPB total score was not associated with the BEHL level, but age was highly correlated with SPPB scores. Besides SPPB scores of gait speed and the chair stand test, actual measuring time was used for multiple linear regressions because the actual time variable can represent more sensitive results than SPPB scores. The results indicated that the gait speed was associated with hearing loss among elderly participants, but the chair stand test time had no relationship with hearing loss.

TUG test results had a similar relationship with hearing impairment similar to the gait speed test. Age was also significantly associated with walking speed among the TUG test. TUG test time would take longer when participants had a severe hearing impairment. The distance from the maximum leg length test also had a negative relationship with hearing

Table 5.5: The impact of hearing level (BEHL) grade on SPPB

	(1)		(2)		(3)	
	Total Score of SPPB		SPPB Gait Speed Time		SPPB Chair Stand Time	
	b	se	b	se	b	se
BEHL 5 grade	-0.220	(0.28)	0.273*	(0.11)	0.894	(0.71)
Male	0.573	(0.35)	-0.195	(0.14)	-2.057*	(0.91)
Age	-0.0893**	(0.03)	0.0367**	(0.01)	0.108	(0.07)
Education	0.0361	(0.37)	-0.00393	(0.15)	-0.434	(0.96)
BMI	0.0116	(0.03)	0.00529	(0.01)	-0.0547	(0.08)
(constant)	16.79**	(3.04)	0.182	(1.23)	7.463	(7.80)
R-Squared overall	0.2282		0.3578		0.1028	
N	30		30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, logit model

loss when controlling for age and sex. However, handgrip strength was not associated with BEHL. Interestingly, sex was a strong predictor of handgrip strength (see Table 5.6).

Table 5.6: The impact of hearing level (BEHL) grade on TUG, maximum leg length, and handgrip strength test

	(1)		(2)		(3)	
	Tug Test Average Time		Leg Test Average Distance		Hand Grip Strength	
	b	se	b	se	b	se
BEHL 5 grade	0.628*	(0.29)	-3.591*	(1.31)	-0.775	(2.05)
Male	-0.571	(0.37)	8.357**	(1.68)	17.91**	(2.62)
Age	0.0880**	(0.03)	-0.409**	(0.13)	-0.314	(0.20)
Education	-0.455	(0.39)	1.003	(1.77)	0.783	(2.77)
BMI	0.00463	(0.03)	-0.161	(0.14)	-0.0376	(0.22)
(constant)	4.423	(3.19)	60.13**	(14.37)	46.24+	(22.47)
R-Squared overall	0.3504		0.5860		0.6559	
N	30		30		30	

$+p < 0.10, *p < 0.05, **p < 0.01$; two-tailed test, logit model

In terms of the cognitive ability test from Table 5.7, MMSE was associated with hearing loss, but the relationship was not strong. Interestingly, education level was highly associated with MMSE scores. Also, the Trail Making Test Part 1 had a positive relationship with BEHL.

Table 5.7: The impact of hearing level (BEHL) grade on cognitive test

	(1)		(2)		(3)		(4)	
	MMSE		TMT(p1)		TMT (p1)		ln(TMT)p2	
	b	se	b	se	b	se	b	se
BEHL 5 grade	-0.659+	(0.38)	2.426	(1.64)			-0.0677	(0.10)
BEHL					0.242*	(0.09)		
Male	0.126	(0.48)	-5.384*	(2.10)	-5.838**	(1.92)	0.0320	(0.13)
Age	-0.0595	(0.04)	0.485**	(0.16)	0.404*	(0.16)	0.0325**	(0.01)
Education	2.012**	(0.51)	-1.320	(2.22)	-1.146	(2.05)	-0.180	(0.14)
BMI	-0.0103	(0.04)	-0.454*	(0.18)	-0.457**	(0.16)	-0.00974	(0.01)
(constant)	24.43**	(4.15)	11.95	(18.03)	14.84	(16.74)	3.016*	(1.14)
R-Squared	0.4594		0.3562		0.4490		0.2193	
N	30		30		30		30	

$+p < 0.10, *p < 0.05, **\, p < 0.01$; two-tailed test, logit model
Model 3 indicates that BEHL (continuous value) is positively associated with TMT (part 1)
Due to the skewness, TMT(part 2) was log-transformed.

5.5 Discussion

Regarding physical abilities based on the test results, some of the test results support previous studies that hearing impairment was strongly, and negatively associated with physical ability. The lower SPPB score was associated with hearing loss that including a mild, moderate, and severe level of hearing impairment [54]. However, SPPB scores including balance, gait speed, and chair stand were not associated with hearing loss according to our findings. Although previous researchers found that hearing impairment was associated with elderly balance ability [68], balance test results from a force plate indicate that balance ability was not associated with a level of hearing impairment when comparing mediolateral and anteroposterior velocity (mm/s) results.

This is not a surprising result because elderly participants in this experiment were relatively healthy in terms of physical and hearing health. Only two elderly participants were diagnosed with moderate hearing loss (BEHL level between 40_{dB} - 60_{dB}). In total 19 participants were diagnosed with no hearing impairment and 9 participants were diagnosed with mild hearing loss. Poor ADL and IADL functions had a strong relationship with the level of hearing loss for participants with mild and moderate level [3]. The total score of ADL was 6-points, for all participants, and the total score of IADL was 8-points for female and 5-points for male participants because 3-points for housekeeping, laundry, and food preparation were excluded for male. Thus, it was hard to analyze the relationship between hearing loss and ADL and IADL because of low variance in the ADL and IADL scores.

According to previous literature, hearing loss is significantly associated with slow gait speed in the elderly [69, 70]. Also, hearing loss increases the odd ratio of individual fall history among the elderly [14]. The findings of this study indicated that walking speed and TUG test showed a positive relationship with mild and moderate hearing loss. however, fall history is not related to the level of hearing loss. After participants had completed the survey during the experiment, a simple interview was conducted by asking the reasons behind their fall. It turned out that most answers were not able to be categorized as fall history because they technically did not fall. Examples include simple miss-steps during yard work or slipping on stairs when they were moving heavy items. To identify the relationship between hearing loss and fall experience and history, more participants are needed especially those who have severe and profound hearing impairment. Cognitive ability is negatively associated with hearing loss among elderly population [6, 71].

Additionally, recruitment of participants with physical limitations should be a target for future research efforts. This would allow for a more representative analysis of different physical capacities and their correlations with hearing loss conditions. Two different types of cognitive ability tests, MMSE and Trail making tests, were conducted for diagnosis of cognitive impairments. Only the Trail Making Test Part 1 was associated with hearing loss when controlling for education level. There was no relationship between MMSE and hearing loss, but the level of education was a strong predictor of MMSE scores. One participant was indicated as an outlier because the participant's BMI was almost 47 with a 17dB BEHL, which indicates no hearing loss. Without the outlier, the apparent relationship was found between hearing loss and physical/cognitive abilities.

5.5.1 Limitations

The small number of elderly participants is a limitation of this study. In addition, it was hard to identify the relationship between physical and cognitive abilities and hearing loss because participants were relatively healthier than their cohort age groups. Based on the fall history survey, the participants reported all types of falling that included incidents such as slipping while carrying heavy items. The survey was not helpful to verify how physical and cognitive impairments relate to hearing loss, and how that relationship increases the risk of a fall.

5.5.2 Strengths

This study conducted physical and cognitive ability tests, as well as the quality-of-life survey test. By conducting physical, cognitive, hearing, and a quality-of-life study at the same time, the findings provide a comprehensive understanding of the relationship between hearing loss and elderly health in terms of physical, and cognitive perspectives.

5.6 Conclusions

Among the elderly participants, hearing loss is related to several physical abilities such as gait speed and flexibility. Also, hearing loss is associated with the decline of cognitive abilities, as seen from the Trail-Making Test result. Various physical and cognitive test such as the SPPB, TUG test, Maximum leg length test, and MMSE display elderly participant's physical and cognitive abilities. Even though participants were relatively healthier than other people their age, the result showed that hearing impairment is still negatively associated with physical and cognitive abilities.

6. CONCLUSIONS

6.1 Summary of Findings

Quality-of-life is one of the most important issues among elderly in 21st century. Particularly, health-related quality-of-life (HRQOL) is determined by various factors including physical, mental and emotional components [27, 72]. Recent research suggested that hearing loss can be a strong factor that is negatively associated with HRQOL along with physical and mental health problems for elderly who aged over 60 [2]. This study provides empirical evidence on this notion that hearing loss is negatively associated with HRQOL by declining physical and mental functional abilities by conducting a 5-year prospective follow up study.

First, hEAR mobile application was validated by comparing with reference hearing test frequencies from the certified audiologists. Only the 8000 Hz frequency test results from the hEAR application show a different result compared to the reference test. In all other frequencies (e.g. 125, 250, 500, 1000, 2000 and 4000 Hz), hEAR application results were statistically similar with the hearing results collected by certified audiologists from Texas ENT. As one of most useful standard methods for determining hearing impairment, the Better Ear Hearing Level (BEHL) is required to have only four frequencies âĂŞ 500, 1000, 2000 and 4000Hz, for measuring hearing loss [51] due to the fact that these frequencies occur in average daily life. Since the hEAR was valid in these frequencies, this experimental study indicates that it can be used as a practical method for determining hearing loss.

Secondly, this study provides evidence that hearing loss was negatively associated with physical and mental health components among quality-of-life index. Particularly, physical, energy/fatigue, emotional and general health components were associated with age-related-hearing-loss among elderly participants. Even though most participants were fairly healthy in terms of mobility and hearing abilities, the experimental results indicates that the likelihood of hearing loss can be related to HRQOL by decreasing physical and mental functional abilities.

Finally, this study indicates that gait speed among the elderly is negatively associated with the hearing loss even after controlling for age, education, sex, and body mass index (BMI). Moreover, this study provides a substantive evidence for the relationship between hearing loss and cognitive abilities by showing the statistically significant result from the Trail-Making Test Part 1 (TMTp1).

The small sample size in this study is a limitation in identifying a relationship between hearing loss and HRQOL. Also, most participants were fairly healthy in terms of mobility and hearing loss metrics. This lack of variability in mobility and hearing loss status was another limitation for determining a link between hearing impairment and HRQOL with whole spectrum of hearing impairment levels (No hearing loss, mild, moderate, severe and profound).

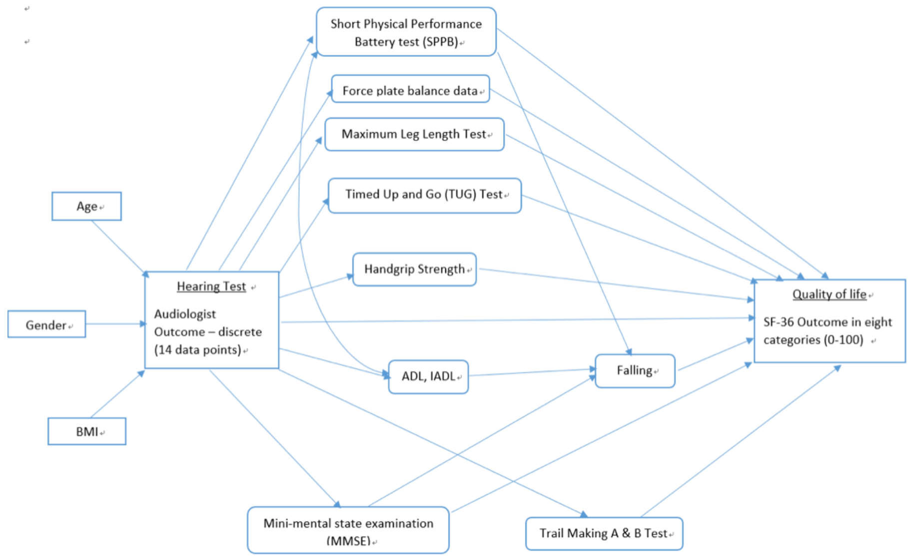
The results were expected to indicate a significant relationship between hearing loss and cognitive functional abilities with a Mini Mental-State Examination (MMSE) because hearing loss associated with declining cognitive abilities was shown based on previous literature. However, the findings only showed a slightly significant relationship because all participants were healthy. On the other hand, hearing loss was not associated with balance abilities when using a force plate. Also, fall histories from individual elderly participants were not associated with hearing impairment due to the participants' healthy records and too few number of fall events.

6.2 Future Work and Research

This study found a comprehensive relationship between bodily functional capacities and hearing loss among the elderly. Further research is needed for a comprehensive structural model and algorithm including hearing loss, HRQOL, physical, mental abilities, and demographic factors.

As an analysis model, the Structural Equation Model (SEM) is an adequate statistical analysis model to develop the predictive quality-of-life evaluation tool related to hearing loss. The SEM provides multiple regressions and factor analysis results by analyzing a structural relation- ship between hearing loss and quality-of-life. There are some assumptions in using SEM such as normality, linearity and free of outlier [73]. Structural equation modeling is one of the most popular statistical modeling methods for behavioral sciences. This is accomplished by analyzing theoretical constructs between observed variables [74]. SEM has been used for predicting health-related quality-of-life for parents of chronically ill children and showed direct and indirect links between having ill children and the parents' quality of life [75]. SEM has also been used to determine key variables that influence the health-related quality-of-life between patients with Marfan Syndrome and their quality-of-life [76]. And, in multiple linear regression analysis models, fatigue and depression level were revealed as significant predictors of health-related quality-of-life among patients with multiple sclerosis [77]. Thus, comprehensive models for relationship between hearing loss and HRQOL can be implemented by using the Structural Equation Model. Figure 6.1, show an example of comprehensive hearing loss and the HRQOL model including potential control factors. The predictive factors of HRQOL with hearing loss are clearly needed for developing interventions for the elderly. The multiple linear/logistic regression and Structural Equation Model are well used for the predictive modeling of HRQOL among elderly population.

Figure 6.1: Structural equation model for the relationship between hearing impairment and health-related quality of life



6.3 Public Health Implications

As the elderly population has been growing, health related quality-of-life has been receiving a lot of attention in our society. Studies have shown hearing loss to be directly tied to overall quality of life among the elderly [61], and hearing loss is one of the fastest growing conditions among the elderly [1]. The findings of this study provide important implications related to hearing loss among the elderly.

1. An automated mobile app can screen for hearing loss in the elderly

2. hEAR mobile app produces audiologist-quality results for elderly individuals with no learning curve

3. Hearing loss is linked to low cognitive functions and declining quality of life in elderly

4. Reduced mobility in elderly tied to hearing loss can lead to quality of life decreases

5. A comprehensive understanding of hearing loss, physical ability, and cognitive capacities can increase health-related quality of life among the elderly.

Elderly individuals are less likely to recognize whether they have an extent of hearing loss until they have a diagnosis test from audiologists. Additionally, only about 20% of the elderly individuals who have hearing loss seek help, and even fewer people recognize how hearing loss influences their quality-of-life [12]. The automation offered by the hEAR mobile application can increase the accessibility for identification of hearing impairment among elderly individuals to include primary care physicians, personal caregivers, and even non-medically trained individuals. A mobile application such as hEAR, even allows elderly individuals self-assess their hearing status to know whether they have hearing loss. Therefore, automated methods such as the hEAR mobile application can potentially serve as an intervention for early-stage detection of hearing loss among the elderly. By using an automated application such as this, early detection of hearing loss among the elderly can be helpful to aid in the provision of hearing aids and other interventions to improve overall quality-of-life. Based on previous research findings and the link between physical cognitive ability improvements and hearing aid use [78] a mobile application with the screening capabilities of the hEAR application has the potential aid improvements in those areas for elderly individuals with hearing loss.

The findings of this research indicate that hearing loss is linked to low cognitive functions and declining quality-of-life in elderly individuals. Lower cognitive functioning associated with hearing loss is directly related to safety issues in daily life. Particularly, reduced cognitive function leads to misunderstanding environmental contexts or miscommunication with others, which may result in hazardous situations. Reduced cognitive abilities associated with hearing loss can also increase the risk of dementia, such as Alzheimer, that decreases their quality-of-life [5]. Knowing this, from an intervention standpoint, early detection of these deficits allows for early intervention shown to increase cognitive functions such as card/board games and puzzles [79]. This early detection and intervention of hearing loss and the subsequent cognitive deficits could lead to delayed cognitive loss and improved overall quality-of-life for many elderly individuals.

Declines in health-related quality-of-life among older adults are also strongly correlated with decreasing physical modalities of motion, such as gait speed, balance, and hearing loss. The findings of this research indicate that decreasing physical functions strongly associated with hearing loss hinders elderly individuals' capability to respond to environmental risks appropriately. Therefore, it is recommended for the elderly to develop physical activities, such as yoga, walking, and exercises as well as appropriate treatment, when they detect hearing loss. Such efforts will increase their overall quality-of-life by reducing the risk of declining physical abilities. The empirical evidence produced by this research contributes to the literature by providing multiple perspectives of hearing loss interventions by considering both cognitive and physical functional abilities related to quality-of-life.

This study expands the perspectives of the relationship between age-related hearing impairment and health-related quality-of-life. Based on the findings of this study, health related quality-of-life can be improved by targeted interventions of physical and cognitive abilities when there is a diagnosis of hearing impairment. This study not only strengthened the relationship between health-related quality-of-life and age-related hearing impairment but also indicated in a significant link between hearing loss and physical/cognitive abilities. For instance, when elderly individuals are diagnosed with hearing loss or even suspect hearing loss in themselves or individuals they care for, they can understand the potential impacts of that hearing loss on their physical and cognitive abilities and their overall health-related quality-of-life. This perspective can serve as a guideline to elderly individuals with hearing loss as to the extent to which their cognitive and physical abilities may be affected and take appropriate intervention methods to counteract those potential impacts on their health-related quality-of-life.

This study contributes to current research in the establishment of a basis of comprehensive understanding of the link between hearing impairment and health-related quality-of-life. The findings will help to build a future multimodal predictive model through advanced algorithm development. Additionally, the results of this research can be used to drive early detection and intervention development for elderly individuals with diagnosed hearing loss. This early detection and intervention of hearing loss through methods such as the automated hEAR application may allow for a dramatic positive impact on the overall health-related quality-of-life in the growing elderly segment of the US and global population.

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APPENDIX A: Consent Form for Participation in a Hearing Research Study

Consent Form for Participation in a Research Study
Texas A&M University

Subject: Developing the predictive quality of life evaluation tool of elderly based on modality of motions and hearing loss.

Description of the research and your participation
You are invited to participate in a research study conducted by Dr. Adam W. Pickens, a researcher from Texas A&M University School of Public Health and No Young You, a doctoral student. The purpose of this research is to collect hearing screening and physical movement data for developing a predictive model. The information in this form is provided to help you decide whether or not to take part. If you decide to take part in the study, you will be asked to sign this consent form. If you decide you do not want to participate, there will be no penalty to you, and you will not lose any benefits you normally would have.

Why is this study being done?
The purpose of this study is to collect pilot data on hearing deficits and functional movement capacities in elderly subjects to begin work on algorithm development for predictive modeling of the relationship between hearing loss and performance on functional movement capacities.

How many people will be asked to be in this study?
The research team recruited via email and fliers locally at Texas A&M University and local community. It is the intent of the research team to recruit a total of approximately 30 total (15 males and 15 females) healthy elderly participants in term of mobility.

What are the alternatives to being in this study?
The alternative to being in the study is not to participate. If you choose not to participate, you will not receive any penalty or lose any benefits you normally would have.

What will I be asked to do in this study?
All participants will be required to provide informed consent prior to participation. Participants will complete two sessions on different or same days: the first session will be laboratory-based physical ability measurements session and the second session will be hearing screening performed by a local audiologist (Texas ENT & Allergy).

<u>1st session:</u> 1st session: At this session, informed consent, demographic and falls history, mental state examination, health testing, and anthropometric measurements will be taken. Included in these measurements will be participant body weight using a digital scale, height using a stadiometer. Participants' functional strength and mobility will be assessed using the Short Physical Performance Battery test (SPPB). SPPB is a well-respected and widely used battery of basic physical performance tests. These tests include balance, gait speed, and chair stand test. Additionally, mobility tests such as the Timed Up and Go (TUG) Test (participants are required to sit in a chair and when given the command, stand and walk 3 meters to a mark on the floor), center of balance test (cm) and Handgrip

Strength Test (HSL – kg) will be conducted. The center of balance data will be collected using a forceplate (participants are required to stand for 20 seconds on a 20"x20" forceplate). Additionally, handgrip strength will be measured by using handgrip dynamometer.

Hearing screening will be conducted using a hearing screening application (mobile hearing screening application – hEAR) during this first session as well. During this test, participants will use a Samsung Galaxy 5 tablet and collect self-administered hearing screening examinations. This will be repeated 3 times per subject. The collection will be through a mobile hearing screening application developed by the PI (hEAR). The application uses algorithms to administer frequency-specific hearing screenings based on audiologist and World Health Organization (WHO) best practices. The application has been used in two previous TAMU-approved pilot studies and has numerous safeguards for volume built into the test algorithms.

Also, elderly participants' cognitive health will be measured by performing Mini-mental state examination (MMSE) and Trail Making Test (TMT). Conducting the Cognitive tests allow research to assess five cognitive abilities such as orientation, attention, registration, recall, and language.

2nd session: Additionally an appointment with a certified audiologist in the Bryan/College Station area will be scheduled for you at your convenience by the investigators. Before the day of the appointment, participants will meet study personnel at SPH to sign the consent form. The audiometry test at the audiologist will similarly be approximately 1 hour. At the appointment, you will be asked to participate in a pure tone audiometric test. The pure tone audiometry used with at the audiologist and with the mobile application will be pure tones ranging from 250 Hz to 8000 Hz randomly for each test period. All expenses regarding the test will be borne by the research team.

Testing Locations

TAMHSC School of Public Health, Department of Environmental and Occupational Health, Laboratory Building Room No. 116, Adriance Lab Road, Raymond Stotzer Parkway, College Station, TX 77843-1266.

Texas ENT &Allergy, 1730 Birmingham Drive College Station, TX77845

Risks and discomforts

The potential harm of the testing procedure, if any, would be that the tones utilized in the trials may be a little aggravating, if at all.

Video Recording

A video and pictures of participants' mobility test time will be recorded for measuring the duration of each physical test. The recording materials will not be associated with participants' personal information**.** This study involves the recording of mobility tests. Neither your name nor any other identifying information will be associated with the recording or the transcript. All data will be coded with a unique identifier. Only the research team will have access to the recordings. Recordings will be transcribed by the researchers, saved as password protected individual files, and saved on password protected TAMU servers. Portions of your interview or individual non-identifiable

answers may be reproduced in whole or in part for use in presentations or written products that result from this study. Neither your name nor any other identifying information (such as your voice or picture) will be used in presentations or in written products resulting from the study. By signing this form, I am allowing the researcher to audio or video tape me as part of this research.
I also understand that this consent for recording is effective until the following date: 8/31/2018.

___________ I give my permission for [photographs/audio/video recordings] to be made of me during my participation in this research study.

Potential benefits
The immediate benefit to subjects is that they will receive a $50 for their participation. The secondary benefit to the subjects would be that their hearing would be tested, and if there is a previously undiscovered hearing disability, then it can be addressed by a qualified audiologist at a later date. Additionally, all costs for the audiologist screening will be covered by the research team.

Protection of confidentiality
All paper reports will be kept in a secure locked cabinet where only the principle investigators will have access to the lock. All paper reports will be assigned a 7-digit uniformly distributed random number that will be unique to each subject. All digital information will be encrypted and stored on the principle investigator's computer that will be password protected, the password only known to investigators. Participant's identity will not be revealed in any publication resulting from this study. No identifiers linking you to this study will be included in any sort of report that might be published. People who have access to your information include the Principle Investigator and research study personnel. Representatives of regulatory agencies such as the Office of Human Research Protections (OHRP) and entities such as the Texas A&M University Human Subjects Protection Program may access your records to make sure the study is being run correctly and that information is collected properly. Information about you and related to this study will be kept confidential to the extent permitted or required by law.

Voluntary participation
Your participation in this research study is voluntary. You may choose not to participate and you may withdraw your consent to participate at any time. You will not be penalized in any way should you decide not to participate or to withdraw from this study.

Contact information
If you have any questions or concerns about this study or if any problems arise, please contact the study PI, Dr. Adam Pickens, at 979-436-9331 or by email at pickens@tamhsc.edu. You can also contact the Research Assistant, No Young You at 979-595-4367 or by email at you@sph.tamhsc.edu. If you have any questions or concerns about your rights as a research participant, please contact the Texas A&M University Institutional Review Board at 979.458.4117.

Consent

I agree to be in this study and know that I am not giving up any legal rights by signing this form. The procedures, risks, and benefits have been explained to me, and my questions have been answered. I know that new information about this research study will be provided to me as it becomes available and that the researcher will tell me if I must be removed from the study. I can ask more questions if I want. A copy of this entire form will be given to me if I so request.

Participant's signature________________________________ Date:_________________

APPENDIX B: Subjects PHI Authorization Form

TEXAS A&M UNIVERSITY HUMAN SUBJECTS PROTECTION PROGRAM

AUTHORIZATION FORM FOR USE AND DISCLOSURE OF PROTECTED HEALTH INFORMATION (PHI) FOR RESEARCH

Project Title: Developing the predictive quality of life evaluation tool of elderly based on modality of motions and hearing loss.

The federal and state governments have issued a privacy rule to protect the privacy rights of individuals enrolled in research. The privacy rule is designed to protect the confidentiality of an individual's health information. This describes your rights and explains how your health information will be used and disclosed for this study.

PURPOSE

You are being invited to participate voluntarily in the above-titled research project. The purpose of collecting Protected Health Information (PHI) for this study is help researchers answer the questions that are being asked in this research study.

WHAT INFORMATION MAY BE USED AND GIVEN TO OTHERS?

Information that will be collected about you includes:

- Hearing exam
- Physical performance test
- Answers to questionnaires about your health

WHO MAY USE AND RECEIVE INFORMATION ABOUT ME?

Information about you may be given out by the Principal Investigator and study personnel to:

- Representatives of regulatory agencies (including Texas A&M University Human Subjects Protection Program) to ensure quality of data and study conduct.
- Texas ENT will receive PHI from this study. Only IRB approved study personnel will have access to the data.

WHY WILL THIS INFORMATION BE USED AND/OR GIVEN TO OTHERS?

This information will be used to understand relationship between hearing deficits and functional movement capacities in elderly subjects. Understanding this is important for therapy and interventions that may improve quality of life for older Americans. In the future, as noted above, with your permission we may share your data with other researchers to develop predictive model.

The results of this research may be published in scientific journals or presented at professional meetings, but your identity will not be revealed.

HOW LONG WILL THIS INFORMATION BE USED AND/OR GIVEN TO OTHERS?

Your PHI will be linked to your identifying information for 2 years after the study is completed. After this time, all links will be destroyed and your identity will not be able to be determined. However, the links between your identity and PHI will be indirect. All information we collect from you will be identified using a number code. The key linking this code to your identifying information will be kept separately, on a secure computer accessible only to the study team members. Both the computer and document with this information will be password-protected. This authorization will expire on the date the research study ends.

MAY I REVIEW OR COPY THE INFORMATION OBTAINED FROM ME OR CREATED ABOUT ME?
You have the right to access your PHI that may be created during this study as it relates to your treatment or payment. Your access to this information will become available only after the study analyses are complete.

MAY I WITHDRAW OR REVOKE (CANCEL) MY PERMISSION?
You may withdraw this authorization at any time by notifying the Principal Investigator in writing. If you choose to withdraw your authorization, any information previously disclosed cannot be withdrawn and may continue to be used. The address for the Principal Investigator is

Adam Pickens,
Environmental and Occupational Health
212 Adriance Lab Rd.
1266 TAMU
College Station, TX 77843-1266

WHAT IF I DECIDE NOT TO GIVE PERMISSION TO USE AND GIVE OUT MY HEALTH INFORMATION?
You may refuse to sign this authorization form. If you choose not to sign this form, you cannot participate in the research study. Refusing to sign will not affect your present or future medical care and will not cause any loss of benefits to which you are otherwise entitled.

IS MY HEALTH INFORMATION PROTECTED AFTER IT HAS BEEN GIVEN TO OTHERS?
Once information about you is disclosed in accordance with this authorization, the individual or organization that receives this may redisclose it and your information may no longer be protected by Federal Privacy Regulations.

CONTACTS
You can obtain further information from the Principal Investigator, Adam Pickens, Ph.D., M.P.H., at pickens@sph.tamhsc.edu or 979-436-9331. If you have questions concerning your rights as a research subject, you may call the Human Subjects Protection Program office at (979) 458-4067 or via email at irb@tamu.edu.

AUTHORIZATION
I hereby authorize the use and disclosure of my individually identifiable health information. I will be given a copy of this signed authorization form.

____ ____________
Subject's Signature Date

____
Printed Name of Subject

____ ____________
Signature of Subject's Legal Representative (if necessary) Date

____
Printed Name of Subject’s Legal Representative

____
Relationship to the Subject

APPENDIX C: Participant Survey Questionnaire

ID # ________________

Participant Survey – About You

Circle the answer that most closely applies.

Ethnicity (Check One):

□ (1) Hispanic or Latino □ (2) Not Hispanic or Latino □ (3) Ethnicity Not Reported

Race (Check ALL that apply):

□ (1) White – Non Hispanic □ (2) White – Hispanic □ (3) American Indian/Alaska Native

□ (4) Asian □ (5) Black or African American □ (6) Native Hawaiian or Pacific Islander

□ (7) Persons Reporting Some Other Race □ (8) Race Not Reported

Sex (Gender): **Age:**____________________

□ Male □ Female

Marital Status (Check One):

□ (1) Married □ (2) Widowed □ (3) Divorced □ (4) Separated □ (5) Never Married □ (6) Not Reported

What is the highest level of education you have completed?

☐ Less than some high school

☐ Some high school

☐ High school graduate

☐ Some college or vocational school

☐ College graduate or higher

Has a health care provider ever told you that you have any of the following chronic conditions? (check ALL that apply.)

□ Arthritis/ Rheumatic Disease

□ Breathing/ Lung Disease (e.g., Asthma, Emphysema, Bronchitis)

□ Cancer

□ Depression or Anxiety Disorders

□ Diabetes

□ Heart Disease

□ Hypertension (High Blood Pressure)

□ Stroke

□ Osteoporosis (Low Bone Density)

□ Other Chronic Condition: ___________________________

ID # _________________

□ None (No Chronic Conditions)

Are you currently taking any medication? If so, please list.

Now think about your physical health, which includes physical illness and injury, for how many days during the past month was your physical health not good?

___________number of days

Now think about your mental health, which includes stress, depression, and problems with emotions, for how many days during the past month was your mental health not good

__________number of days

During the past month, for about how many days did poor physical or mental health keep you from doing your usual activities, such as self-care, work, or recreation?

__________number of days

How would you rate your overall quality of life? (Please circle the number below that describes your quality of life in the past month):

0	1	2	3	4	5	6	7	8	9	10

Very poor — Excellent quality

Over the past month, how often have you been bothered by any of the following problems?

	Not at all	Several days	More than half the days	Nearly every day
Taking a walk	□	□	□	□
Jogging	□	□	□	□
Lifting light item	□	□	□	□
Little interest or pleasure in doing things	□	□	□	□
Feeling down, depressed or hopeless	□	□	□	□

Over the past month, how often has your health interfered with the following?

	Often	Sometimes	Seldom	Never
Your hobbies or recreational activities?	□	□	□	□
Your household chores?	□	□	□	□

ID # ________________

Your errands & shopping?	□	□	□	□

PARTICIPANT SURVEY- FALLS

In the <u>past month</u>, how many times have you fallen? (By fall, we mean when a person unintentionally comes to rest on the ground or another level)

__________ times

In the <u>past year</u>, how many times have you fallen? (By fall, we mean when a person unintentionally comes to rest on the ground or another level)

___________ times

How many of these falls caused an injury? (By injury, we mean the fall caused you to limit your regular activities for at least a day or go to see a doctor)

_____________ times

How fearful are you of falling?

□ Not at all □ A little □ Somewhat □ A lot

To what extent has your concern about falling interfered with your normal social activities with family, friends, neighbors or groups?

□ Extremely □ Quite a bit □ Moderately □ Slightly □ Not at all

How would you rate your:

	Excellent	Very Good	Good	Fair	Poor
Steadiness on your feet					
Balance while walking					
Ability to walk in your home					
Ability to walk outdoors					
Ability to prevent falls					
Ability to find a way to get up if you fall					

ID # ________________

PARTICIPANT SURVEY- Exercise

Are you presently exercising?

□ Yes □ No

If you answered yes: How long have you been exercising?

□ Less than 3 months □ 3 - 6 months □ 6 - 12 months □ More than 1 year □ More than 2 year

How many days per week?

□ 1 □ 2 □ 3 □ 4 □ 5 □ 6 □ 7

How much time can you comfortably allocate per workout session based on your lifestyle?

□ Less than 15 minutes □ 15 - 30 minutes □ 30 - 45 minutes □ 45 – 60 minutes □ Over 60 minutes

What type of exercise do you usually do? (Apply all)

□ Walking □ Jogging/Running □ Biking/Cycling □ Aerobics □ swimming

□ Non-aerobic □ Weight lifting □ Tunnies □ Golf □ Baseball

□ Basketball □ Others (____)

Rate yourself on a scale of 1 to 5 (1 indicating the lowest, 5 the highest)

Aerobic (endurance) fitness level □ 1 □ 2 □ 3 □ 4 □ 5

Muscular (strength) level □ 1 □ 2 □ 3 □ 4 □ 5

Flexibility level □ 1 □ 2 □ 3 □ 4 □ 5

APPENDIX D: MOS 36-Item Short-Form Health Survey Questionnaire

SF36 Health Survey

INSTRUCTIONS: This set of questions asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. Answer every question by marking the answer as indicated. If you are unsure about how to answer a question please give the best answer you can.

1. In general, would you say your health is: (Please tick **one** box.)
   - Excellent ☐
   - Very Good ☐
   - Good ☐
   - Fair ☐
   - Poor ☐

2. Compared to one year ago, how would you rate your health in general now? (Please tick **one** box.)
   - Much better than one year ago ☐
   - Somewhat better now than one year ago ☐
   - About the same as one year ago ☐
   - Somewhat worse now than one year ago ☐
   - Much worse now than one year ago ☐

3. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much? **(Please circle one number on each line.)**

	Activities	Yes, Limited A Lot	Yes, Limited A Little	Not Limited At All
3(a)	**Vigorous activities**, such as running, lifting heavy objects, participating in strenuous sports	1	2	3
3(b)	**Moderate activities**, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	1	2	3
3(c)	Lifting or carrying groceries	1	2	3
3(d)	Climbing **several** flights of stairs	1	2	3
3(e)	Climbing **one** flight of stairs	1	2	3
3(f)	Bending, kneeling, or stooping	1	2	3
3(g)	Waling **more than a mile**	1	2	3
3(h)	Walking **several blocks**	1	2	3
3(i)	Walking **one block**	1	2	3
3(j)	Bathing or dressing yourself	1	2	3

4. During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

	(Please circle one number on each line.)	Yes	No
4(a)	Cut down on the **amount of time** you spent on work or other activities	1	2
4(b)	Accomplished less than you would like	1	2
4(c)	Were **limited** in the **kind** of work or other activities	1	2
4(d)	Had **difficulty** performing the work or other activities (for example, it took extra effort)	1	2

5. During the past 4 weeks, have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (e.g. feeling depressed or anxious)?

	(Please circle one number on each line.)	Yes	No
5(a)	Cut down on the **amount of time** you spent on work or other activities	1	2
5(b)	Accomplished less than you would like	1	2
5(c)	Didn't do work or other activities as **carefully** as usual	1	2

6. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbours, or groups? (Please tick **one** box.)

- Not at all ☐
- Slightly ☐
- Moderately ☐
- Quite a bit ☐
- Extremely ☐

7. How much physical pain have you had during the past 4 weeks? (Please tick **one** box.)

- None ☐
- Very mild ☐
- Mild ☐
- Moderate ☐
- Severe ☐
- Very Severe ☐

8. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)? (Please tick **one** box.)

- Not at all ☐
- A little bit ☐
- Moderately ☐
- Quite a bit ☐
- Extremely ☐

9. These questions are about how you feel and how things have been with you during the past 4 weeks. Please give the one answer that is closest to the way you have been feeling for each item.

	(Please circle one number on each line.)	**All of the Time**	**Most of the Time**	**A Good Bit of the Time**	**Some of the Time**	**A Little of the Time**	**None of the Time**
9(a)	Did you feel full of life?	1	2	3	4	5	6
9(b)	Have you been a very nervous person?	1	2	3	4	5	6
9(c)	Have you felt so down in the dumps that nothing could cheer you up?	1	2	3	4	5	6
9(d)	Have you felt calm and peaceful?	1	2	3	4	5	6
9(e)	Did you have a lot of energy?	1	2	3	4	5	6
9(f)	Have you felt downhearted and blue?	1	2	3	4	5	6
9(g)	Did you feel worn out?	1	2	3	4	5	6
9(h)	Have you been a happy person?	1	2	3	4	5	6
9(i)	Did you feel tired?	1	2	3	4	5	6

10. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives etc.) (Please tick **one** box.)

- All of the time ☐
- Most of the time ☐
- Some of the time ☐
- A little of the time ☐
- None of the time ☐

11. How TRUE or FALSE is each of the following statements for you?

	(Please circle one number on each line.)	**Definitely True**	**Mostly True**	**Don't Know**	**Mostly False**	**Definitely False**
11(a)	I seem to get sick a little easier than other people	1	2	3	4	5
11(b)	I am as healthy as anybody I know	1	2	3	4	5
11(c)	I expect my health to get worse	1	2	3	4	5
11(d)	My health is excellent	1	2	3	4	5

APPENDIX E: Activities of Daily Living (ADLs) and Instrumental Activities of Daily Living (IADLs) Questionnaire

Patient Name:______________________ **Date:_____________**
Patient ID #________________________

Katz Index of Independence in Activities of Daily Living

Activities Points (1 or 0)	**Independence** (1 Point) **NO** supervision, direction or personal assistance.	**Dependence** (0 Points) **WITH** supervision, direction, personal assistance or total care.
BATHING Points: __________	**(1 POINT)** Bathes self completely or needs help in bathing only a single part of the body such as the back, genital area or disabled extremity.	**(0 POINTS)** Need help with bathing more than one part of the body, getting in or out of the tub or shower. Requires total bathing
DRESSING Points: __________	**(1 POINT)** Get clothes from closets and drawers and puts on clothes and outer garments complete with fasteners. May have help tying shoes.	**(0 POINTS)** Needs help with dressing self or needs to be completely dressed.
TOILETING Points: __________	**(1 POINT)** Goes to toilet, gets on and off, arranges clothes, cleans genital area without help.	**(0 POINTS)** Needs help transferring to the toilet, cleaning self or uses bedpan or commode.
TRANSFERRING Points: __________	**(1 POINT)** Moves in and out of bed or chair unassisted. Mechanical transfer aids are acceptable	**(0 POINTS)** Needs help in moving from bed to chair or requires a complete transfer.
CONTINENCE Points: __________	**(1 POINT)** Exercises complete self control over urination and defecation.	**(0 POINTS)** Is partially or totally incontinent of bowel or bladder
FEEDING Points: __________	**(1 POINT)** Gets food from plate into mouth without help. Preparation of food may be done by another person.	**(0 POINTS)** Needs partial or total help with feeding or requires parenteral feeding.
TOTAL POINTS: ________	**SCORING:** 6 = High (*patient independent*) 0 = Low (*patient very dependent*	

Source:
try this: Best Practices in Nursing Care to Older Adults, The Hartford Institute for Geriatric Nursing, New York University, College of Nursing, www.hartfordign.org.

Patient Name:______________________ **Date:**_____________

Patient ID #________________________

LAWTON - BRODY
INSTRUMENTAL ACTIVITIES OF DAILY LIVING SCALE (I.A.D.L.)

Scoring: For each category, circle the item description that most closely resembles the client's highest functional level (either 0 or 1).

A. Ability to Use Telephone		**E. Laundry**	
1. Operates telephone on own initiative-looks up and dials numbers, etc.	1	1. Does personal laundry completely	1
2. Dials a few well-known numbers	1	2. Launders small items-rinses stockings, etc.	1
3. Answers telephone but does not dial	1	3. All laundry must be done by others	0
4. Does not use telephone at all	0		
B. Shopping		**F. Mode of Transportation**	
1. Takes care of all shopping needs independently	1	1. Travels independently on public transportation or drives own car	1
2. Shops independently for small purchases	0	2. Arranges own travel via taxi, but does not otherwise use public transportation	1
3. Needs to be accompanied on any shopping trip	0	3. Travels on public transportation when accompanied by another	1
4. Completely unable to shop	0	4. Travel limited to taxi or automobile with assistance of another	0
		5. Does not travel at all	0
C. Food Preparation		**G. Responsibility for Own Medications**	
1. Plans, prepares and serves adequate meals independently	1	1. Is responsible for taking medication in correct dosages at correct time	1
2. Prepares adequate meals if supplied with ingredients	0	2. Takes responsibility if medication is prepared in advance in separate dosage	0
3. Heats, serves and prepares meals, or prepares meals, or prepares meals but does not maintain adequate diet	0	3. Is not capable of dispensing own medication	0
4. Needs to have meals prepared and served	0		
D. Housekeeping		**H. Ability to Handle Finances**	
1. Maintains house alone or with occasional assistance (e.g. "heavy work domestic help")	1	1. Manages financial matters independently (budgets, writes checks, pays rent, bills, goes to bank), collects and keeps track of income	1
2. Performs light daily tasks such as dish washing, bed making	1	2. Manages day-to-day purchases, but needs help with banking, major purchases, etc.	1
3. Performs light daily tasks but cannot maintain acceptable level of cleanliness	1	3. Incapable of handling money	0
4. Needs help with all home maintenance tasks	1		
5. Does not participate in any housekeeping tasks	0		
Score		**Score**	

Total score__________________

A summary score ranges from 0 (low function, dependent) to 8 (high function, independent) for women and 0 through 5 for men to avoid potential gender bias.

Source: *try this:* Best Practices in Nursing Care to Older Adults, The Hartford Institute for Geriatric N[illegible]
New York University, College of Nursing, www.hartfordign.org.

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general assessment series
Best Practices in Nursing Care to Older Adults
From The Hartford Institute for Geriatric Nursing, New York University, College of Nursing

Issue Number 2, Revised 2007

Series Editor: Marie Boltz, PhD, GNP-BC
Series Co-Editor: Sherry A. Greenberg, MSN, GNP-BC
New York University College of Nursing

Katz Index of Independence in Activities of Daily Living (ADL)

By: Meredith Wallace, PhD, APRN, BC, Fairfield University School of Nursing, and Mary Shelkey, PhD, ARNP, Virginia Mason Medical Center

WHY: Normal aging changes and health problems frequently show themselves as declines in the functional status of older adults. Decline may place the older adult on a spiral of iatrogenesis leading to further health problems. One of the best ways to evaluate the health status of older adults is through functional assessment which provides objective data that may indicate future decline or improvement in health status, allowing the nurse to intervene appropriately.

BEST TOOL: The Katz Index of Independence in Activities of Daily Living, commonly referred to as the Katz ADL, is the most appropriate instrument to assess functional status as a measurement of the client's ability to perform activities of daily living independently. Clinicians typically use the tool to detect problems in performing activities of daily living and to plan care accordingly. The Index ranks adequacy of performance in the six functions of *bathing, dressing, toileting, transferring, continence, and feeding*. Clients are scored yes/no for independence in each of the six functions. A score of 6 indicates full function, 4 indicates moderate impairment, and 2 or less indicates severe functional impairment.

TARGET POPULATION: The instrument is most effectively used among older adults in a variety of care settings, when baseline measurements, taken when the client is well, are compared to periodic or subsequent measures.

VALIDITY AND RELIABILITY: In the thirty-five years since the instrument has been developed, it has been modified and simplified and different approaches to scoring have been used. However, it has consistently demonstrated its utility in evaluating functional status in the elderly population. Although no formal reliability and validity reports could be found in the literature, the tool is used extensively as a flag signaling functional capabilities of older adults in clinical and home environments.

STRENGTHS AND LIMITATIONS: The Katz ADL Index assesses basic activities of daily living. It does not assess more advanced activities of daily living. Katz developed another scale for instrumental activities of daily living such as heavy housework, shopping, managing finances and telephoning. Although the Katz ADL Index is sensitive to changes in declining health status, it is limited in its ability to measure small increments of change seen in the rehabilitation of older adults. A full comprehensive geriatric assessment should follow when appropriate. The Katz ADL Index is very useful in creating a common language about patient function for all practitioners involved in overall care planning and discharge planning.

MORE ON THE TOPIC:

Best practice information on care of older adults: www.ConsultGeriRN.org.
Graf, C. (2006). Functional decline in hospitalized older adults. *AJN, 106*(1), 58-67.
Katz, S., Down, T.D., Cash, H.R., & Grotz, R.C. (1970) Progress in the development of the index of ADL. *The Gerontologist*, *10*(1), 20-30.
Katz, S. (1983). Assessing self-maintenance: Activities of daily living, mobility and instrumental activities of daily living. *JAGS*, *31*(12), 721-726.
Kresevic, D.M., & Mezey, M. (2003). Assessment of function. In M. Mezey, T. Fulmer, I. Abraham (Eds.), D. Zwicker (Managing Ed.), *Geriatric nursing protocols for best practice* (2nd ed., pp 31-46). NY: Springer Publishing Co., Inc.
Mick, D.J., & Ackerman, M.H. (2004, Sept). Critical care nursing for older adults: Pathophysiological and functional considerations. *Nursing Clinics of North America*, *39*(3), 473-93.

try this: Best Practices in Nursing Care to Older Adults
from The Hartford Institute for Geriatric Nursing
New York University, College of Nursing

Issue Number 23, Revised 2007

Series Editor: Marie Boltz, PhD, APRN, BC, GNP
Managing Editor: Sherry A. Greenberg, MSN, APRN, BC, GNP
New York University College of Nursing

The Lawton Instrumental Activities of Daily Living (IADL) Scale

By: Carla Graf, MS, APRN, BC, University of California, San Francisco

WHY: The assessment of functional status is critical when caring for older adults. Normal aging changes, acute illness, worsening chronic illness, and hospitalization can contribute to a decline in the ability to perform tasks necessary to live independently in the community. The information from a functional assessment can provide objective data to assist with targeting individualized rehabilitation needs or to plan for specific in home services such as meal preparation, nursing care, home-maker services, personal care, or continuous supervision. A functional assessment can also assist the clinician to focus on the person's baseline capabilities, facilitating early recognition of changes that may signify a need either for additional resources or for a medical work-up (Gallo, 2006).

BEST TOOL: The Lawton Instrumental Activities of Daily Living Scale (IADL) is an appropriate instrument to assess independent living skills (Lawton & Brody, 1969). These skills are considered more complex than the basic activities of daily living as measured by the Katz Index of ADLs (See *Try this*: Katz Index of ADLs). The instrument is most useful for identifying how a person is functioning at the present time, and to identify improvement or deterioration over time. There are eight domains of function measured with the Lawton IADL scale. Women are scored on all 8 areas of function; historically, for men, the areas of food preparation, housekeeping, laundering are excluded. Clients are scored according to their highest level of functioning in that category. A summary score ranges from 0 (low function, dependent) to 8 (high function, independent) for women, and 0 through 5 for men.

TARGET POPULATION: This instrument is intended to be used among older adults, and can be used in community or hospital settings. The instrument is not useful for institutionalized older adults. It can be used as a baseline assessment tool and to compare baseline function to periodic assessments.

VALIDITY AND RELIABILITY: Few studies have been performed to test the Lawton IADL scale psychometric properties. The Lawton IADL Scale was originally tested concurrently with the Physical Self-Maintenance Scale (PSMS). Reliability was established with twelve subjects interviewed by one interviewer with the second rater present but not participating in the interview process. Inter-rater reliability was established at .85. The validity of the Lawton IADL was tested by determining the correlation of the Lawton IADL with four scales that measured domains of functional status, the Physical Classification (6-point rating of physical health), Mental Status Questionnaire (10-point test of orientation and memory), Behavior and Adjustment rating scales (4-6-point measure of intellectual, person, behavioral and social adjustment), and the PSMS (6-item ADLs). A total of 180 research subjects participated in the study, however, few received all five evaluations. All correlations were significant at the .01 or .05 level. To avoid potential gender bias at the time the instrument was developed, specific items were omitted for men. This assessment instrument is widely used both in research and in clinical practice.

STRENGTHS AND LIMITATIONS: The Lawton IADL is an easy to administer assessment instrument that provides self-reported information about functional skills necessary to live in the community. Administration time is 10-15 minutes. Specific deficits identified can assist nurses and other disciplines in planning for safe discharge.
Limitations of the instrument can include the self-report or surrogate report method of administration rather than a demonstration of the functional task. This may lead either to over-estimation or under-estimation of ability. In addition, the instrument may not be sensitive to small, incremental changes in function.

FOLLOW-UP: The identification of new disabilities in these functional domains warrants intervention and further assessment to prevent ongoing decline and to promote safe living conditions for older adults. If using the Lawton IADL tool with an acute hospitalization, nurses should communicate any deficits to the physicians and social workers/case managers for appropriate discharge planning.

MORE ON THE TOPIC:

Best practice information on care of older adults: www.ConsultGeriRN.org.

Gallo, J.J., & Paveza, G.J. (2006). Activities of daily living and instrumental activities of daily living assessment. In J.J. Gallo, H.R. Bogner, T. Fulmer, & G.J. Paveza (Eds.), *Handbook of Geriatric Assessment* (4th ed., pp. 193-240). MA: Jones and Bartlett Publishers.

Graf, C. (2006). Functional decline in hospitalized older adults. *AJN, 106*(1), 58-67.

Lawton, M.P., & Brody, E.M. (1969). Assessment of older people: Self-maintaining and instrumental activities of daily living. *The Gerontologist, 9*(3), 179-186.

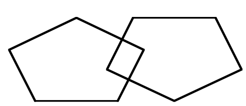
Pearson, V. (2000). Assessment of function. In R. Kane, & R. Kane (Eds.), *Assessing Older Persons. Measures, Meaning and Practical Applications* (pp. 17-48). New York: Oxford University Press.

APPENDIX F: Mini-Mental State Examination (MMSE) Cognitive Test Sheet

Mini-Mental State Examination (MMSE)

Patient's Name: ____ Date: ______________

Instructions: Score one point for each correct response within each question or activity.

Maximum Score	Patient's Score	Questions
5		"What is the year? Season? Date? Day? Month?"
5		"Where are we now? State? County? Town/city? Hospital? Floor?"
3		The examiner names three unrelated objects clearly and slowly, then the instructor asks the patient to name all three of them. The patient's response is used for scoring. The examiner repeats them until patient learns all of them, if possible.
5		"I would like you to count backward from 100 by sevens." (93, 86, 79, 72, 65, …) Alternative: "Spell WORLD backwards." (D-L-R-O-W)
3		"Earlier I told you the names of three things. Can you tell me what those were?"
2		Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.
1		"Repeat the phrase: 'No ifs, ands, or buts.'"
3		"Take the paper in your right hand, fold it in half, and put it on the floor." (The examiner gives the patient a piece of blank paper.)
1		"Please read this and do what it says." (Written instruction is "Close your eyes.")
1		"Make up and write a sentence about anything." (This sentence must contain a noun and a verb.)
1		"Please copy this picture." (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.) 
30		TOTAL

Interpretation of the MMSE:

Method	Score	Interpretation
Single Cutoff	<24	Abnormal
Range	<21	Increased odds of dementia
	>25	Decreased odds of dementia
Education	21	Abnormal for 8th grade education
	<23	Abnormal for high school education
	<24	Abnormal for college education
Severity	24-30	No cognitive impairment
	18-23	Mild cognitive impairment
	0-17	Severe cognitive impairment

Interpretation of MMSE Scores:

Score	Degree of Impairment	Formal Psychometric Assessment	Day-to-Day Functioning
25-30	Questionably significant	If clinical signs of cognitive impairment are present, formal assessment of cognition may be valuable.	May have clinically significant but mild deficits. Likely to affect only most demanding activities of daily living.
20-25	Mild	Formal assessment may be helpful to better determine pattern and extent of deficits.	Significant effect. May require some supervision, support and assistance.
10-20	Moderate	Formal assessment may be helpful if there are specific clinical indications.	Clear impairment. May require 24-hour supervision.
0-10	Severe	Patient not likely to be testable.	Marked impairment. Likely to require 24-hour supervision and assistance with ADL.

Source:

- Folstein MF, Folstein SE, McHugh PR: "Mini-mental state: A practical method for grading the cognitive state of patients for the clinician." *J Psychiatr Res* 1975;12:189-198.

APPENDIX G: Trail Making Test Sheet

Trail Making Test (TMT) Parts A & B

Instructions:

Both parts of the Trail Making Test consist of 25 circles distributed over a sheet of paper. In Part A, the circles are numbered 1 – 25, and the patient should draw lines to connect the numbers in ascending order. In Part B, the circles include both numbers (1 – 13) and letters (A – L); as in Part A, the patient draws lines to connect the circles in an ascending pattern, but with the added task of alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). The patient should be instructed to connect the circles as quickly as possible, without lifting the pen or pencil from the paper. Time the patient as he or she connects the "trail." If the patient makes an error, point it out immediately and allow the patient to correct it. Errors affect the patient's score only in that the correction of errors is included in the completion time for the task. It is unnecessary to continue the test if the patient has not completed both parts after five minutes have elapsed.

Step 1: Give the patient a copy of the Trail Making Test Part A worksheet and a pen or pencil.

Step 2: Demonstrate the test to the patient using the sample sheet (Trail Making Part A – *SAMPLE*).

Step 3: Time the patient as he or she follows the “trail” made by the numbers on the test.

Step 4: Record the time.

Step 5: Repeat the procedure for Trail Making Test Part B.

Scoring:

Results for both TMT A and B are reported as the number of seconds required to complete the task; therefore, higher scores reveal greater impairment.

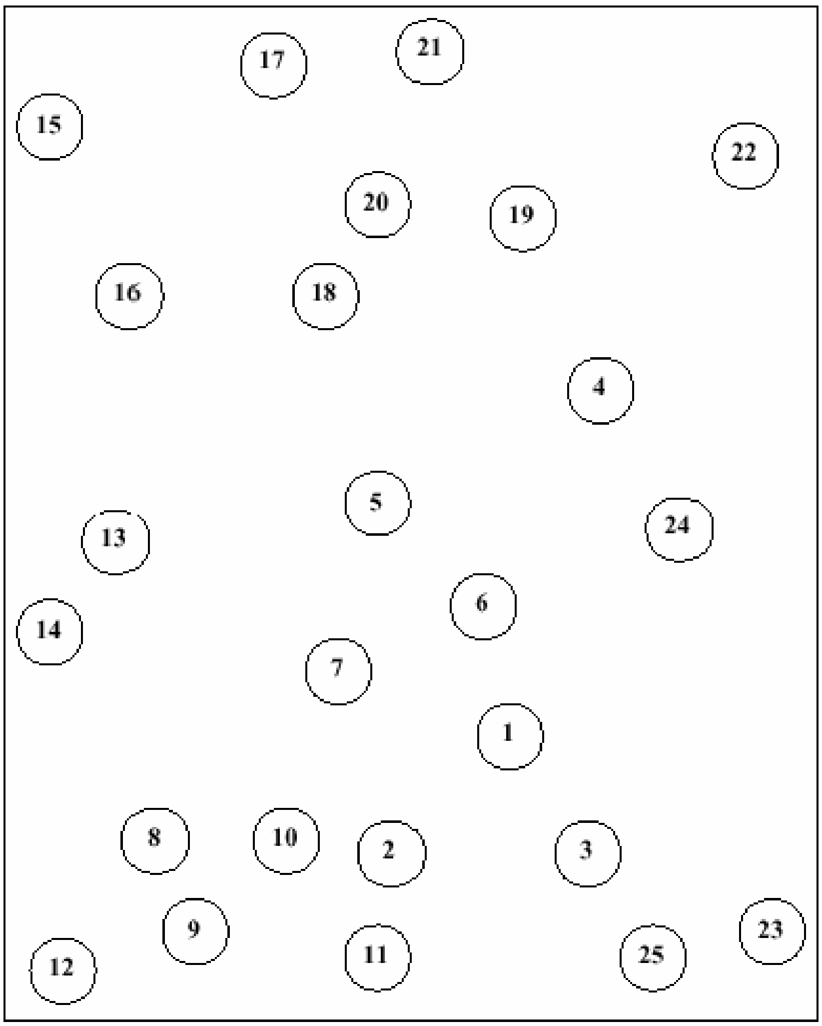
	Average	**Deficient**	**Rule of Thumb**
Trail A	29 seconds	> 78 seconds	Most in 90 seconds
Trail B	75 seconds	> 273 seconds	Most in 3 minutes

Sources:

- Corrigan JD, Hinkeldey MS. Relationships between parts A and B of the Trail Making Test. *J Clin Psychol*. 1987;43(4):402–409.
- Gaudino EA, Geisler MW, Squires NK. Construct validity in the Trail Making Test: what makes Part B harder? *J Clin Exp Neuropsychol*. 1995;17(4):529-535.
- Lezak MD, Howieson DB, Loring DW. *Neuropsychological Assessment*. 4th ed. New York: Oxford University Press; 2004.
- Reitan RM. Validity of the Trail Making test as an indicator of organic brain damage. *Percept Mot Skills*. 1958;8:271-276.

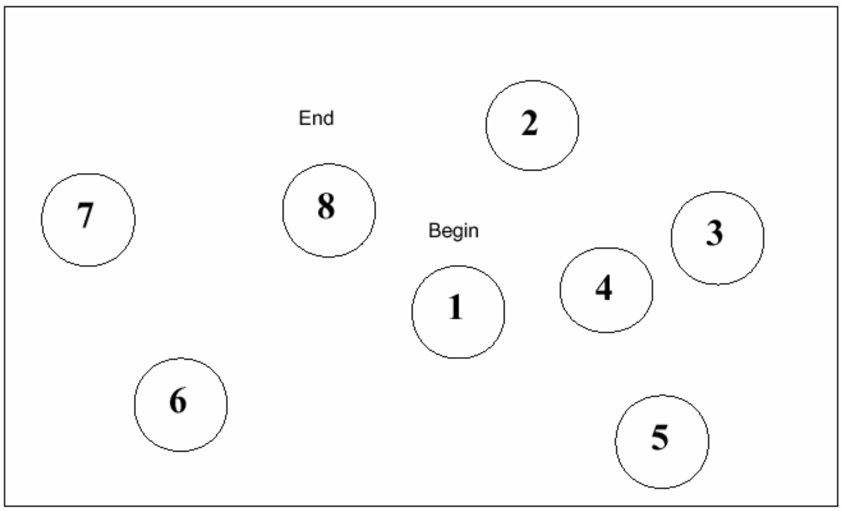
Trail Making Test Part A

Patient's Name: ______________________________ Date: ____________________



IRB NUMBER: IRB2016-0806D
IRB APPROVAL DATE: 01/19/2017
IRB EXPIRATION DATE: 01/15/2018

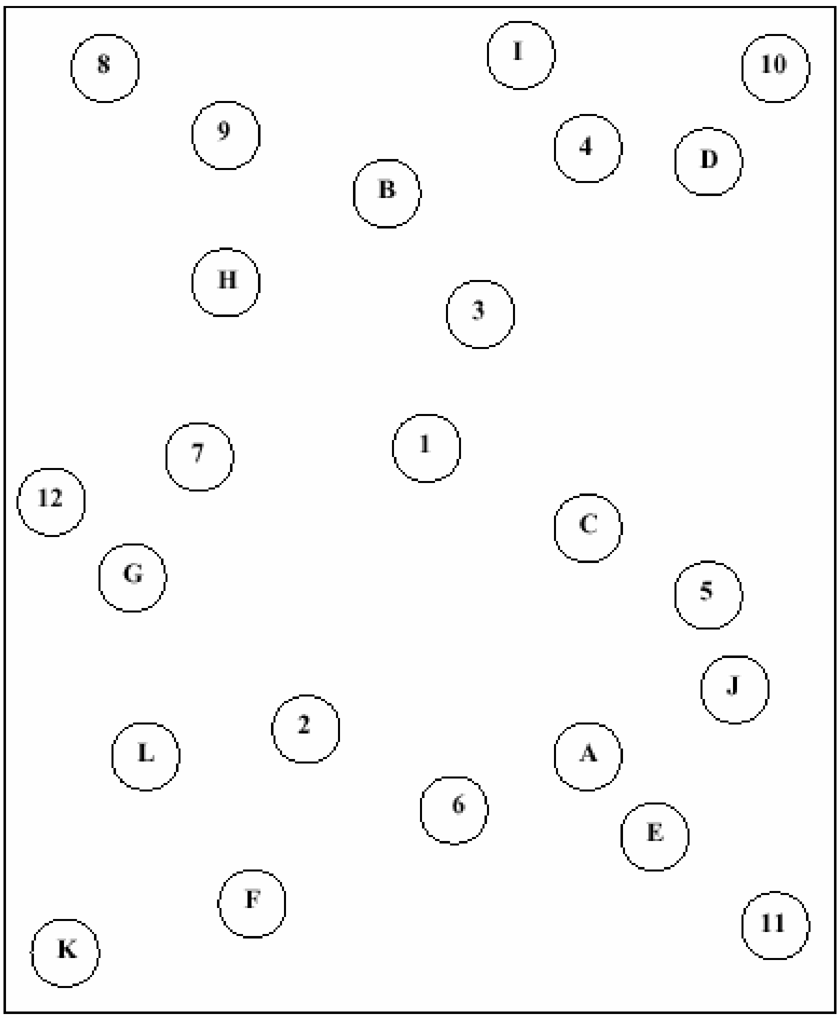
Trail Making Test Part A – *SAMPLE*



IRB NUMBER: IRB2016-0806D
IRB APPROVAL DATE: 01/19/2017
IRB EXPIRATION DATE: 01/15/2018

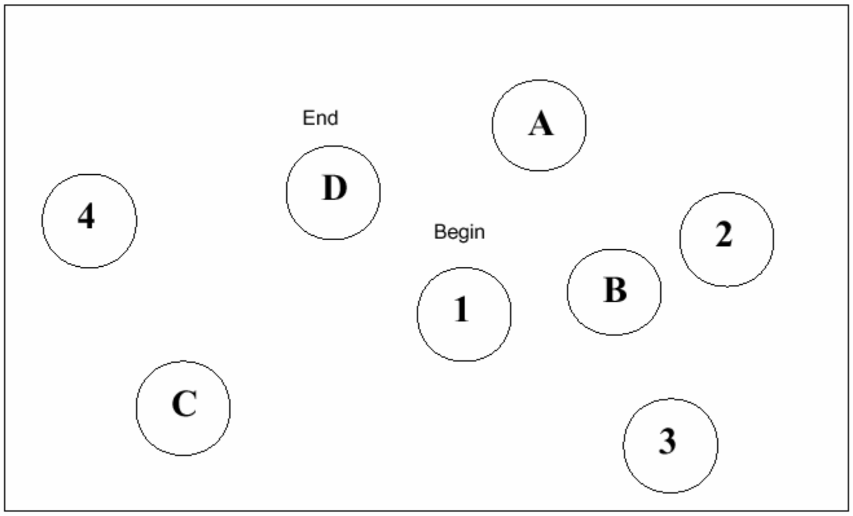
Trail Making Test Part B

Patient's Name: ______________________________ Date: ____________________



IRB NUMBER: IRB2016-0806D
IRB APPROVAL DATE: 01/19/2017
IRB EXPIRATION DATE: 01/15/2018

Trail Making Test Part B – *SAMPLE*



APPENDIX H: Short Physical Performance Battery (SPPB) - Protocol

Study ID ______________________ Date ___________________ Tester Initials ____________________

SHORT PHYSICAL PERFORMANCE BATTERY PROTOCOL AND SCORE SHEET

All of the tests should be performed in the same order as they are presented in this protocol. Instructions to the participants are shown in bold italic and should be given exactly as they are written in this script.

1. BALANCE TESTS

The participant must be able to stand unassisted without the use of a cane or walker. You may help the participant to get up.

> ***Now let's begin the evaluation. I would now like you to try to move your body in different movements. I will first describe and show each movement to you. Then I'd like you to try to do it. If you cannot do a particular movement, or if you feel it would be unsafe to try to do it, tell me and we'll move on to the next one. Let me emphasize that I do not want you to try to do any exercise that you feel might be unsafe.***
>
> ***Do you have any questions before we begin?***

A. Side-by-Side Stand

1. ***Now I will show you the first movement***.
2. (Demonstrate) ***I want you to try to stand with your feet together, side-by-side, for about 10 seconds.***
3. ***You may use your arms, bend your knees, or move your body to maintain your balance, but try not to move your feet. Try to hold this position until I tell you to stop.***
4. Stand next to the participant to help him/her into the side-by-side position.
5. Supply just enough support to the participant's arm to prevent loss of balance.
6. When the participant has his/her feet together, ask ***"Are you ready?"***
7. Then let go and begin timing as you say, ***"Ready, begin."***
8. Stop the stopwatch and say ***"Stop"*** after 10 seconds or when the participant steps out of position or grabs your arm.
9. If participant is unable to hold the position for 10 seconds, record result and go to the gait speed test.

Study ID ______________________ Date ___________________ Tester Initials ____________________

B. Semi-Tandem Stand

1. ***Now I will show you the second movement***.

2. (Demonstrate) ***Now I want you to try to stand with the side of the heel of one foot touching the big toe of the other foot for about 10 seconds. You may put either foot in front, whichever is more comfortable for you.***

3. ***You may use your arms, bend your knees, or move your body to maintain your balance, but try not to move your feet. Try to hold this position until I tell you to stop.***

4. Stand next to the participant to help him/her into the semi-tandem position

5. Supply just enough support to the participant's arm to prevent loss of balance.

6. When the participant has his/her feet together, ask ***"Are you ready?"***

7. Then let go and begin timing as you say ***"Ready, begin."***

8. Stop the stopwatch and say ***"Stop"*** after 10 seconds or when the participant steps out of position or grabs your arm.

9. If participant is unable to hold the position for 10 seconds, record result and go to the gait speed test.

C. Tandem Stand

1. ***Now I will show you the third movement***.

2. (Demonstrate) ***Now I want you to try to stand with the heel of one foot in front of and touching the toes of the other foot for about 10 seconds. You may put either foot in front, whichever is more comfortable for you.***

3. ***You may use your arms, bend your knees, or move your body to maintain your balance, but try not to move your feet. Try to hold this position until I tell you to stop.***

4. Stand next to the participant to help him/her into the tandem position.

5. Supply just enough support to the participant's arm to prevent loss of balance.

6. When the participant has his/her feet together, ask ***"Are you ready?"***

7. Then let go and begin timing as you say, ***"Ready, begin."***

8. Stop the stopwatch and say ***"Stop"*** after 10 seconds or when the participant steps out of position or grabs your arm.

IRB NUMBER: IRB2016-0806D
IRB APPROVAL DATE: 01/19/2017
IRB EXPIRATION DATE: 01/15/2018

Study ID ______________________ Date ___________________ Tester Initials ____________________

SCORING:

A. Side-by-side-stand

Held for 10 sec ❒ 1 point
Not held for 10 sec ❒ 0 points
Not attempted ❒ 0 points
If 0 points, end Balance Tests

Number of seconds held if
less than 10 sec: ___.__ __sec

If participant did not attempt test or failed, circle why:

Tried but unable	1
Participant could not hold position unassisted	2
Not attempted, you felt unsafe	3
Not attempted, participant felt unsafe	4
Participant unable to understand instructions	5
Other (specify) __________________________	6
Participant refused	7

B. Semi-Tandem Stand

Held for 10 sec ❒ 1 point
Not held for 10 sec ❒ 0 points
Not attempted ❒ 0 points *(circle reason above)*
If 0 points, end Balance Tests

Number of seconds held if less than 10 sec: ___.__ __sec

C. Tandem Stand

Held for 10 sec ❒ 2 points
Held for 3 to 9.99 sec ❒ 1 point
Held for < than 3 sec ❒ 0 points
Not attempted ❒ 0 points (circle reason above)

Number of seconds held if less than 10 sec: ___.__ __sec

D. Total Balance Tests score__________(sum points)

Comments: ____

____

____

____

____

____

____

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2. GAIT SPEED TEST
Now I am going to observe how you normally walk. If you use a cane or other walking aid and you feel you need it to walk a short distance, then you may use it.

A. First Gait Speed Test

1. ***This is our walking course. I want you to walk to the other end of the course at your usual speed, just as if you were walking down the street to go to the store.***

2. Demonstrate the walk for the participant.

3. ***Walk all the way past the other end of the tape before you stop. I will walk with you. Do you feel this would be safe?***

4. Have the participant stand with both feet touching the starting line.

5. ***When I want you to start, I will say: "Ready, begin."*** When the participant acknowledges this instruction say: ***"Ready, begin."***

6. Press the start/stop button to start the stopwatch as the participant begins walking.

7. Walk behind and to the side of the participant.

8. Stop timing when one of the participant's feet is completely across the end line.

B. Second Gait Speed Test

1. ***Now I want you to repeat the walk. Remember to walk at your usual pace, and go all the way past the other end of the course.***

2. Have the participant stand with both feet touching the starting line.

3. ***When I want you to start, I will say: "Ready, begin."*** When the participant acknowledges this instruction say: ***"Ready, begin."***

4. Press the start/stop button to start the stopwatch as the participant begins walking.

5. Walk behind and to the side of the participant.

6. Stop timing when one of the participant's feet is completely across the end line.

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GAIT SPEED TEST SCORING:

Length of walk test course: Four meters ❐ Three meters ❐

A. Time for First Gait Speed Test (sec)

1. Time for 3 or 4 meters __ __.__ __sec
2. If participant did not attempt test or failed, circle why:

Tried but unable	1
Participant could not walk unassisted	2
Not attempted, you felt unsafe	3
Not attempted, participant felt unsafe	4
Participant unable to understand instructions	5
Other (Specify) ______________________	6
Participant refused	7

Complete score sheet and go to chair stand test

3. Aids for first walk...............None ❐ Cane ❐ Other ❐

Comments:____

____

____

B. Time for Second Gait Speed Test (sec)

1. Time for 3 or 4 meters __ __.__ __ sec
2. If participant did not attempt test or failed, circle why:

Tried but unable	1
Participant could not walk unassisted	2
Not attempted, you felt unsafe	3
Not attempted, participant felt unsafe	4
Participant unable to understand instructions	5
Other (Specify)	6
Participant refused	7

3. Aids for second walk............ None ❐ Cane ❐ Other ❐

What is the time for the faster of the two walks?
Record the shorter of the two times __ __.__ __ sec
[If only 1 walk done, record that time] __ __.__ __ sec

If the participant was unable to do the walk: ❐ **0 points**

For 4-Meter Walk:

If time is more than 8.70 sec:	❐ **1 point**
If time is 6.21 to 8.70 sec:	❐ **2 points**
If time is 4.82 to 6.20 sec:	❐ **3 points**
If time is less than 4.82 sec:	❐ **4 points**

For 3-Meter Walk:

If time is more than 6.52 sec:	❐ **1 point**
If time is 4.66 to 6.52 sec:	❐ **2 points**
If time is 3.62 to 4.65 sec:	❐ **3 points**
If time is less than 3.6	❐ **4 points**

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3. CHAIR STAND TEST

Single Chair Stand

1. ***Let's do the last movement test. Do you think it would be safe for you to try to stand up from a chair without using your arms?***

2. ***The next test measures the strength in your legs.***

3. (Demonstrate and explain the procedure.) ***First, fold your arms across your chest and sit so that your feet are on the floor; then stand up keeping your arms folded across your chest.***

4. ***Please stand up keeping your arms folded across your chest.*** (Record result).

5. If participant cannot rise without using arms, say ***"Okay, try to stand up using your arms."*** This is the end of their test. Record result and go to the scoring page.

Repeated Chair Stands

1. ***Do you think it would be safe for you to try to stand up from a chair five times without using your arms?***

2. (Demonstrate and explain the procedure): ***Please stand up straight as QUICKLY as you can five times, without stopping in between. After standing up each time, sit down and then stand up again. Keep your arms folded across your chest. I'll be timing you with a stopwatch.***

3. When the participant is properly seated, say: ***"Ready? Stand"*** and begin timing.

4. Count out loud as the participant arises each time, up to five times.

5. Stop if participant becomes tired or short of breath during repeated chair stands.

6. Stop the stopwatch when he/she has straightened up completely for the fifth time.

7. Also stop:
   - If participant uses his/her arms
   - After 1 minute, if participant has not completed rises
   - At your discretion, if concerned for participant's safety

8. If the participant stops and appears to be fatigued before completing the five stands, confirm this by asking ***"Can you continue?"***

9. If participant says "Yes," continue timing. If participant says "No," stop and reset the stopwatch.

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SCORING
Single Chair Stand Test

		YES	**NO**
A.	Safe to stand without help	❒	❒

B. Results:

Participant stood without using arms	❒	→ Go to Repeated Chair Stand Test
Participant used arms to stand	❒	→ End test; score as 0 points
Test not completed	❒	→ End test; score as 0 points

C. If participant did not attempt test or failed, circle why:

Tried but unable	1
Participant could not stand unassisted	2
Not attempted, you felt unsafe	3
Not attempted, participant felt unsafe	4
Participant unable to understand instructions	5
Other (Specify) _________________________________	6
Participant refused	7

Repeated Chair Stand Test

		YES	**NO**
A.	Safe to stand five times	❒	❒

B. If five stands done successfully, record time in seconds.

Time to complete five stands __ __.__ __ sec

C. If participant did not attempt test or failed, circle why:

Tried but unable	1
Participant could not stand unassisted	2
Not attempted, you felt unsafe	3
Not attempted, participant felt unsafe	4
Participant unable to understand instructions	5
Other (Specify)	6
Participant refused	7

Scoring the Repeated Chair Test

Participant unable to complete 5 chair stands or completes stands in >60 sec:	❒ 0 points
If chair stand time is 16.70 sec or more:	❒ 1 points
If chair stand time is 13.70 to 16.69 sec:	❒ 2 points
If chair stand time is 11.20 to 13.69 sec:	❒ 3 points
If chair stand time is 11.19 sec or less:	points

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Scoring for Complete Short Physical Performance Battery

Test Scores
Total Balance Test score _____ **points**
Gait Speed Test score _____ **points**
Chair Stand Test score _____ **points**

Total Score _____ **points (sum of points above)**

APPENDIX I: The Timed Up and Go (TUG) Test Sheet

Patient: ______________________ Date: ________ Time: ________ AM/PM

The Timed Up and Go (TUG) Test

Purpose: To assess mobility

Equipment: A stopwatch

Directions: Patients wear their regular footwear and can use a walking aid if needed. Begin by having the patient sit back in a standard arm chair and identify a line 3 meters or 10 feet away on the floor.

Instructions to the patient:

When I say **"Go,"** I want you to:

1. Stand up from the chair
2. Walk to the line on the floor at your normal pace
3. Turn
4. Walk back to the chair at your normal pace
5. Sit down again

On the word **"Go"** begin timing.

Stop timing after patient has sat back down and record.

Time: _________ **seconds**

An older adult who takes ≥12 seconds to complete the TUG is at high risk for falling.

Observe the patient's postural stability, gait, stride length, and sway.

Circle all that apply: Slow tentative pace ■ Loss of balance ■ Short strides ■ Little or no arm swing ■ Steadying self on walls ■ Shuffling ■ En bloc turning ■ Not using assistive device properly

Notes:

For relevant articles, go to: **www.cdc.gov/injury/STEADI**

Centers for Disease Control and Prevention
National Center for Injury Prevention and Control

STEADI Stopping Elderly Accidents, Deaths & Injuries

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APPENDIX J: Recruitment Flyer

PUBLIC HEALTH
TEXAS A&M UNIVERSITY

Participants Needed

Study: Developing the predictive model of functionality evaluation of elderly based on joint measurement, modality of motions and hearing loss.

You are invited to participate in a study evaluating the validity of data collected by a mobile hearing screening application conducted by Dr. Adam Pickens at Texas A&M School of Public Health (SPH).

The study involves one (1) approximately two-hour visit to SPH and one (1) approximately one-hour visit to a local certified audiologist.

You will be paid $50 for study participation.

If you are 60-80 years of age, are willing to undergo audiometric and physical ability testing, willing to answer brief questions about your activities related to hearing ability, and would like more information about participation, contact No Young You at you@sph.tamhsc.edu.

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APPENDIX K: Recruitment email script

Email script for "**Developing the predictive quality of life evaluation tool of elderly based on modality of motions and hearing loss.**"

TO: All Texas A&M University employees.

SUBJECT: Participants needed for SPH hearing and physical ability study

BODY:
TAMU employees are invited to participate in a new study (approved TAMU IRB number: NNN) developing for predictive modeling of the relationship between hearing loss and performance on functional movement capacities.

All participants will be required to provide informed consent prior to participation. Participants will complete two sessions on different or same days: the first session will be two-hours laboratory-based physical ability measurements session in the SPH Lab (TAMHSC School of Public Health, Department of Environmental and Occupational Health, Laboratory Building Room 116,) and the second session will be one-hour hearing screening performed by a local audiologist (Texas ENT & Allergy).

Any TAMU employee and elderly in local community who meets the following criteria is welcome to participate in the study:

Participants must:
Inclusion criteria:

1. Participant age is 60-80 years of age.
2. Participant is in normal health in terms of mobility.
3. Participant needs to English proficient.

Exclusion criteria:

1. Individuals with self-reported injuries or medical condition that interfere with the data collection.
2. Individuals who use hearing aid or have serious diagnosed hearing impairment.
3. Individuals who use crutches, wheelchair, and any walking aid.

If you would like more information about the study, or to schedule a time to participate, please contact the experimenter at the contact info below. Participation slots are limited, so don't delay! Please feel free to forward this email to any other students who might be interested in the study.